WINDS, STABILITY, AND
TWENTY-FOUR HOUR SULFUR DIOXIDE CONCENTRATIONS
IN METROPOLITAN SAINT LOUIS

by

Eric Walther, B. S. in Education

A Digest Presented to the Faculty of the Graduate School
of Saint Louis University in Partial Fulfillment
of the Requirements for the Degree
of Master of Science (Research)

1965

DIGEST

A study of the relationships between wind, vertical temperature data, and twenty-four hour sulfur dioxide concentration data, collected from December 5, 1963 to February 28, 1963, was made. The sulfur dioxide samples were collected at twenty sampling sites in the St. Louis metropolitan area.

KMOX-TV tower, located in the central commercial and industrial section of the metropolitan area, was instrumented with three aspirated thermal sensing units, placed at 127, 249, and 452 feet above the ground. Two anemometers were installed, one at the 127 foot level and one at the 452 foot level. Wind recording stations in north, west and south sections of the metropolitan area were utilized. The recorded meterorological data were reduced to average hourly values by the Public Health Service's, Taft Sanitary Engineering Center, Cincinnati, Ohio.

The assumption of uniform sulfur dioxide pollution during the twenty-four hour period was made. The temperature-differences recorded at the TV tower were classified into five stability categories; superadiabatic dry-adiabatic, lapse, isothermal, and inversion. The wind data were reduced to sixteen direction intervals.

The sulfur dioxide concentrations were related to the stability categories and wind direction. The average pollution concentration was determined for each stability category and wind interval at each sampling site. The

four highest average concentrations, taken from pollution roses, generally indicated the center of the metropolitan area as the primary pollution source. A large number of the stronger than average concentrations occurred in other than stable conditions. This would indicated that "fumigation" is an important process in this area.

An analysis of the vertical temperature structure, recorded by the thermal sensing units on the KMOX TV tower, showed the 249-452 feet layer to be more unstable than the 127-249 feet layer when hourly frequencies of the stability categories were considered. An atmospheric stability, topography, and sulfur dioxide relationship showed all sampling sites located above 500 feet mean sea level experienced maximum average stability-concentrations only during stable conditions in the 249-542 feet layer. There was no build-up in the sulfur dioxide concentrations indicated during the longer stable periods.

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1965

COMMITTEE IN CHARGE OF CANDILACY

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CONVENTIONS AND SYMBOLS

COH is defined as coefficient of haze.

$$COH = 100 \log_{10} \frac{\text{Intensity of transmitted light through the clean paper}}{\text{Intensity of transmitted light through the soiled paper.}}$$ (33)

Concentration-day--corresponds to time sulfur dioxide samplers were started and stopped. 1400 to 1400 twenty-four hours later.

HT--the difference between two levels in feet.

F--degrees Fahrenheit.

Lapse Rate Classification:

D--dry-adiabatic
L--lapse (between dry-adiabatic and isothermal)
Is--isothermal
S--superadiabatic

MPH--miles per hour

MSG--missing data

PPHM--parts per hundred million

MSL--mean sea level

PPM--parts per million

SITE--sulfur dioxide sampling site listed in Appendix

STATION-wind recording stations listed in Appendix

TAL--127-452 foot layer on KMOX TV Tower

THL--249-452 foot layer on KMOX TV Tower

TLL--127-249 foot layer on KMOX TV Tower

Time will be in the 2400 hour clock Central Standard Time

Wind Observing Stations

W-1 Lindbergh High School
W-2 State Highway Patrol Station (Ballas Road and Highway 40)
W-3 Hazelwood High School
W-4 Bottom KMOX TV Tower
W-5 Top KMOX TV Tower

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CHAPTER I

INTRODUCTION

The problem of air pollution is not what one would call a new one. Wood was "the fuel" through earlier periods of history; as the forests became denuded a need for a substitute arose. With the introduction of coal, approximately in the 13th century, the problem of air pollution was born. Coal was considered an "unnatural" fuel; its sulfurous combustion products confirmed its suspected association with anticlerical forces. The use of coal gave rise to neighborhood "action committees" to protest against its evident pollution of the atmosphere.

In England, Germany and elsewhere on the continent various limitations to the use, importation, and transportation of coal were proclaimed. In isolated instances there is evidence that capital penalties were imposed (5).

Earlier efforts at control centered around smoke primarily and later gases; principally, sulfur dioxide. Chambers (5) relates,

> "In 1661 a most remarkable pamphlet was published by royal command of Charles II. It consisted of an essay entitled, 'Fumifugium: or the Inconvenience of the Air and Smoke of London Dissipated; together with some remedies Humbly Proposed,' written by John Evelyn. It is unfortunate that the author's 17th

> Century style has attracted more attention in the 20th Century than has the content of his paper. Evelyn clearly recognized the sources, and the broad aspects of the control problem, to an extent not far surpassed today except for detail and for chemical and physiological terminology."

Hammon et al (14) compared minimum temperatures, from 1891 to 1895 inclusive, between a Forest Park Meteorological observatory, located about one half mile from the mid point of the east park boundary, and the United States Weather Bureau Station, located at Eighth and Olive Streets in St. Louis.

The Weather Bureau instrument shelter was situated 110 feet above street level and 10 feet above a copper roof. In contrast the Forest Park shelter was 10 feet above the sod.

An average difference of plus 4.6F in minimum temperatures was noted for the urban area compared to Forest Park. This evidenced the heat island phenomena. Hammon et al commented that the excess smoke over the city was probably the cause for the difference. This is one of the earlier published air pollution observations in St. Louis.

G. V. Williamson (38), in an address to the 56th Annual Meeting of the Air Pollution Control Association in 1964 commented,

> "Air Pollution control (with very few exceptions such as the special field of fallout) is concerned to, shall we say, the lowest 1500 yards of our atmosphere. Nor is it concerned, despite occasional efforts to so extend it, to every part of our land mass, or 48 states. It can be pinpointed to a limited number of isolated places and, by all odds, mostly to air within a few miles beyond the periphery of larger cities. Circles of perhaps a twenty mile radius would cover the preponderant numbers of major centers."

These limitations of Williamson do not seem to be warranted by the facts. During this author's three year residence at Portsmouth, New Hampshire, as a meteorologist, visibility was frequently reduced by pollutants which migrated a minimum of forty miles so that a good rule of thumb for visibility forecasting was, "Under anticyclonic influence and a sustained southerly to southwesterly flow of twenty-four hours or more decrease the normal ten miles plus visibility to six or seven miles and after forty-eight hours decrease it to a maximum of four to five miles." The cause of the decreased visibility did not originate within twenty miles, but from a part of the megaopolis which extends from Boston to Washington, D. C.

The Los Angeles Basin and the Oxnard Plain are separated by an extension of the San Gabriel Mountains. The author of this thesis was a forecaster at Oxnard Air

Force Base, California for two years. Forecasters, at Oxnard, noted that a sustained southeasterly flow along the coast advected the pollution thirty to forty miles from the Los Angeles Basin into the Oxnard Plain. Here, too, the arrival of pollution drastically reduces visibility.

Bringing the problem closer to home, in April, 1964, while flying between St. Louis and Cincinnati, this author followed the metropolitan St. Louis smoke plume to a power plant located on the Wabash River, just northeast of Hutsonville, Illinois, a distance of one hundred forty miles. The plume was still well defined. Due to more pressing matters, I was forced to discontinue my observation. As recently as 1000 Central Standard Time, 20 February 1965, while flying to Memphis, this author noticed a well defined smoke plume passing over Blytheville, Arkansas. The smoke was streaming up from the south-southeast. I followed it to a factory located on the northern outskirts of Memphis. The distance travelled was in excess of fifty miles. These are but four examples of pollution extending well beyond the twenty mile limit as proposed by Williamson.

To what degree these constitute a health hazard has yet to be determined. Thus, we cannot pull our heads into our shells claiming only a relatively small area is

affected, and likewise, we cannot gallop off on our white chargers and indiscriminately place limitations on industry, or for that matter, on the automobile, bus and truck drivers or the heating of residences, etc. The metropolitan area needs industry, as much as industry needs the metropolitan area. The basic aspect of the complex problem of air pollution demands urgent attention. We must come to an understanding on the medical implications of air pollution; to set realistic standards, as well as reasonable and economical control methods.

It is hoped that this paper will reveal some of the meteorological factors that influence variations of sulfur dioxide concentrations in the St. Louis Metropolitan area.

REVIEW OF RELATED LITERATURE

GENERAL

The fatalities associated with the infamous smogs of December, 1952 at London, England and at Donora, Pennsylvania in October, 1948 have drawn attention to the health aspects of air pollution. The undesirability of sulfur dioxide in the atmosphere has been recognized because of its highly irritating effect on the respiratory system, its adverse effect on plant life in concentrations as low as 0.3 PPM. An insidious side of air pollution is that of property damage. It is estimated the annual cost to the nation is over $11 billion.

> "Sulfur dioxide, a common contaminant in the air of virtually all towns and cities, causes deterioration of many materials. It attacks metals, particularly iron and steel. Limestone, marble, roofing slate, mortar, and other carbonate-containing stone, are partially converted to water-soluble sulfates, which are leached away by rain. Sulfur dioxide has an affinity for leather, causing it to weaken and rot. Costly damage to upholstery and book bindings has been produced by its action. Cotton, wool, and nylon are all weakened by sulfur dioxide." (30)

Bienstock, Field and Benson (4) point out that since World War II there has been an increased usage of low sulfur content fuels. But as these fuels become less available and fuel demands become greater, more higher-sulfur content fuels must be used. Though there has been an improvement in recent years on the sulfur dioxide emission by use of low-sulfur fuels, the problem again

looms on the horizon. There are two general methods of approach to the control of sulfur dioxide emission into the atmosphere; either by removal of sulfur from the fuel prior to combustion, or by removal of sulfur dioxide from the products of combustion. Bienstock, Field and Benson discuss various processes for both types of control. It is pointed out in their discussion that there is concern of depletion of the sources of raw sulfur for use in industrial processes, and yet, in the United States, the total amount of sulfur emitted to the air by burning fuels is larger than the amount of raw sulfur mined plus the amount imported.

Fletcher (12) analysed the "Donora Smog Disaster" showing the primary causes to be:

1. Pollution sources nearby and active,

2. Topography,

3. The lower atmospheric layers having great stability, and weak winds blowing from the pollutant source,

4. Humidity in the lowest layers such that fogs formed and persisted,

5. Large scale synoptic conditions were stagnant for a minimum of four days.

Church (6) classified smoke plumes according to visible characteristics (figure 2) and analysed these classifications for typical occurrence, stability, wind, turbulence conditions, characteristic dispersion, and

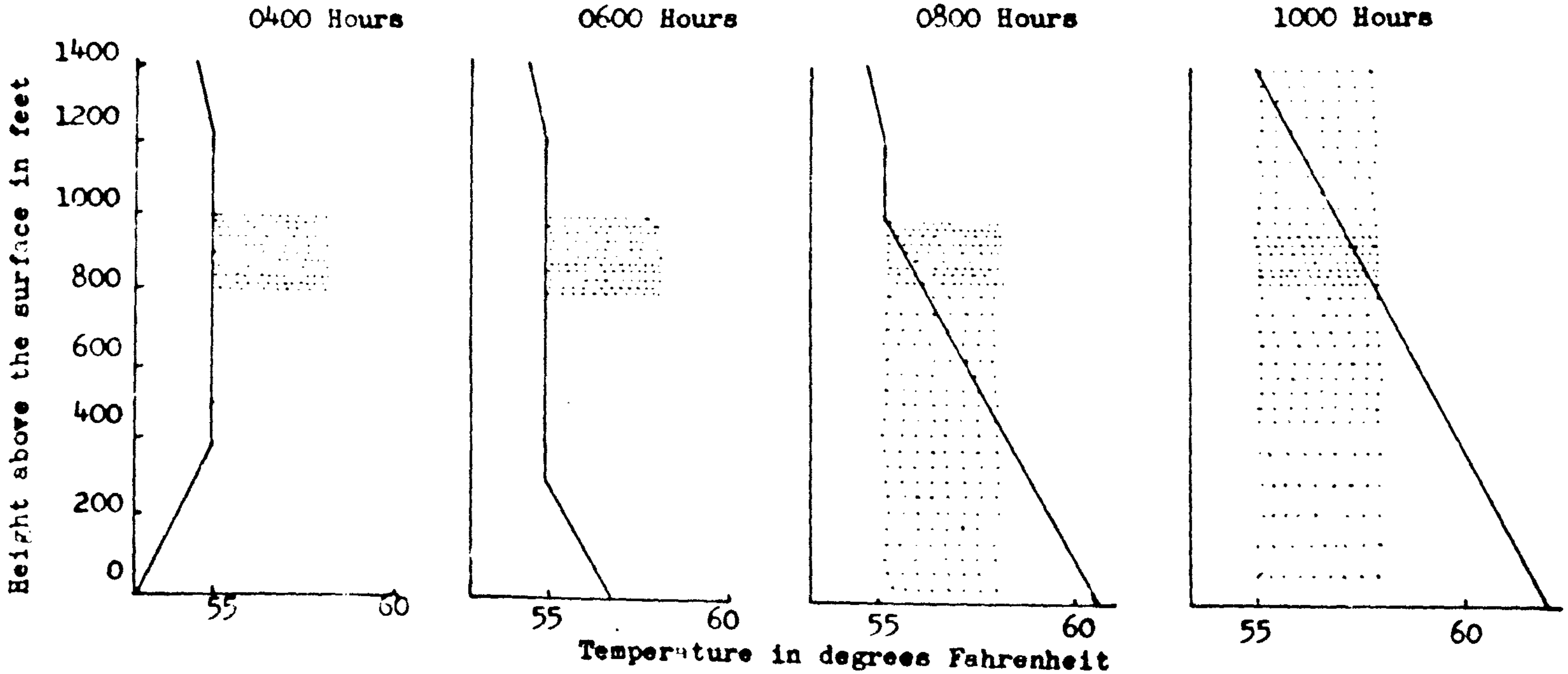
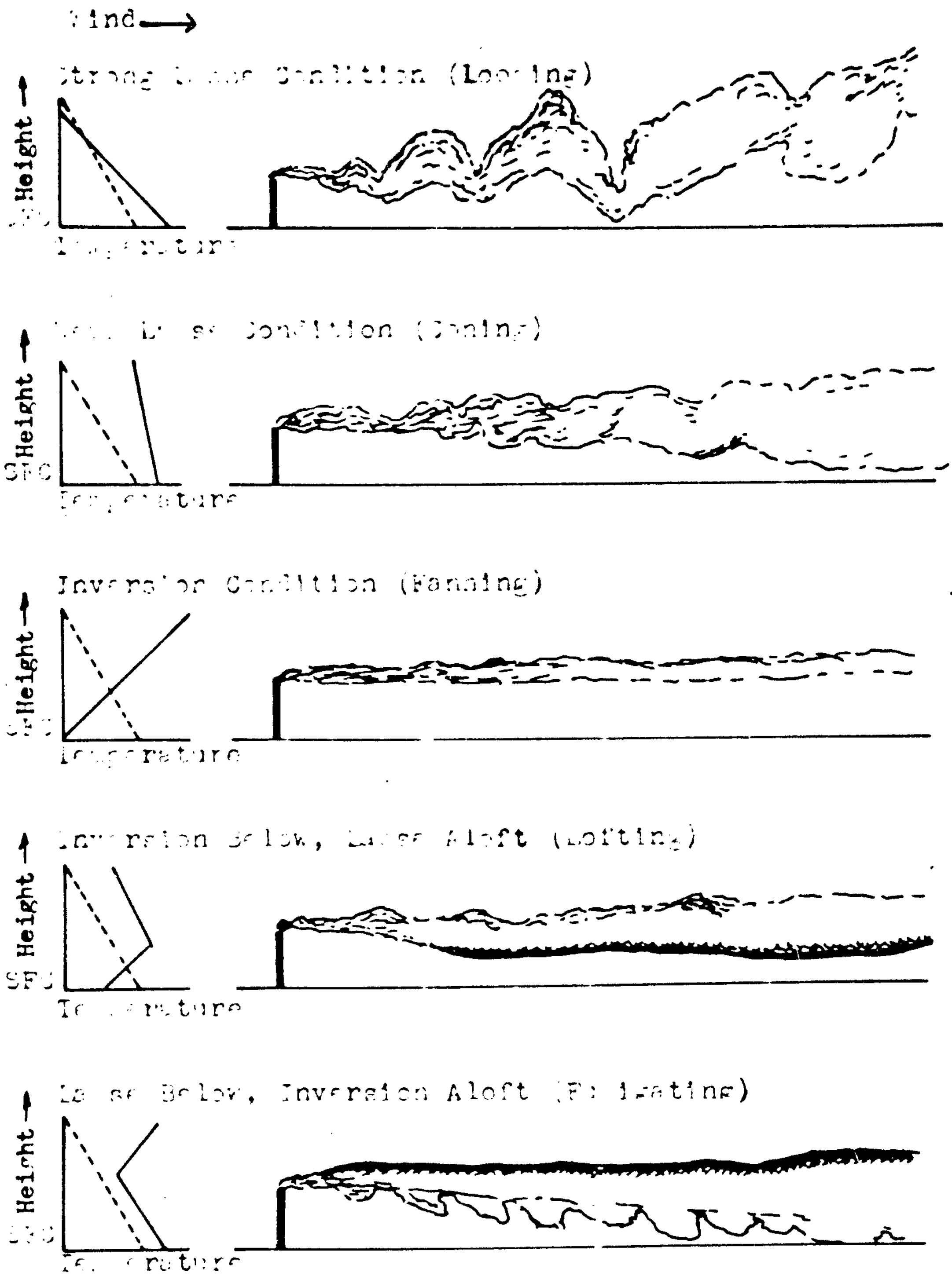


Figure 1. Hewson Fumigation
Various stages in the process by which contaminants from an elevated source reach the ground in high concentrations during a summer morning, according to Hewson (15).



Dash line represents dry adiabatic rate

Figure 2. Plume Behavior and Related Weather (Church 5)

ground contact. It should be noted, invisible emitted gases will assume these same dispersion characteristics under like atmospheric conditions.

Thus, it is evident, the relationship of the height of the emitting stack to that of the inversion is most important. One cannot stop with the mere height of the stack, but must consider the virtual stack height, dependent on:

a. volume rate, b. effluent temperature, c. ambient air temperature, d. ambient air temperature lapse rate, e. effluent density at a stated temperature, f. effluent velocity, g. wind speed, h. stack diameter.

Dean et al (8) investigated a very severe pollution problem associated with a smelter at Trail British Columbia, Canada, located in the Columbia River Valley. Hewson and Gill (8) performed a very detailed analysis on the meteorological variants. It was determined that there were several types of atmospheric pollution traps. One, that of an inversion capping the area with light winds below the inversion allowing little lateral and vertical diffusion and the pollution extending from the ground to the base of the inversion. A second type known as "fumigation" is shown by the sequence of events in figure 1. An isothermal layer, or inversion layer, must be situated a short distance above the top of a smoke stack. The emitted pollution stabilizes at the "virtual stack height (6)." The only dispersion is due to the wind, which is usually light. Thus, there is a high

concentration of pollution aloft. The sun heats the surfase, which in turn heats the layer of surface air, producing a superadiabatic condition, and marked turbulence. As the upper boundary of the turbulent surface layer moves upward into the layer of highly concentrated pollutants aloft, then the pollutants very rapidly descend, producing nearly simultaneous fumigation over the area. As the upper boundary of the turbulent layer continues to rise upward, diffusion of the gas proceeds, leading to exponentially decreasing surface concentration, thereafter. This author noted a condition of this type at Twelfth and Market Streets during January, 1964 at 0900 hours. The smoke billowing downward appeared as a well developed mammatus type cloud. When it reached the surface, the air became very acrid and caused one to cough. The visibility at street level prior to the fumigation was at least three miles. With the advent of fumigation, the visibility decreased to at best one-half mile.

Gartrell et. al. (13) attempted to derive a formula which would give ground level sulfur dioxide concentrations resulting from single source emitters. Applying Sutton's (32) diffusion equation to averaged conditions, they found fair correlation, but when applied to specific instances, they found wide discrepancies. They were dealing with concentration changes of intervals hourly or less. It was pointed out that

stacks, which emit below an inversion, frequently send up gases which are hot enough to break through inversions; thus, decreasing the concentrations in the lower level below anticipated values.

Hosler (20) compiled seasonal and annual frequencies for low level inversions over the United States. The data consisted of two year samples, and he considered only the frequency of inversions and/or isothermal layers based at or below 500 feet above station elevation. The nocturnal period was considered stable if an inversion was observed on the soundings. He did not consider any daylight inversions. He felt the above assumption did not seriously invalidate his findings through comparison of selected instrumented towers and close by radiosonde observations. This author feels it would certainly weigh the observations toward increased inversion frequency. Statistical study was made of the relationship of night time cloud cover and wind speed to inversion frequency. Poor correlation was found between these parameters for all seasons. It was noted that the radiosonde stations located at airports are located on the outskirts of cities; thus, the inversion frequencies are representative, for the most part, of nocturnal inversions of a semi-rural or suburban area. Consequently, one would expect to find lower frequencies for central city area due to mechanical turbulence and heat effects imposed by large metropolitan area.

Landsberg (21) shows the following effect of a typically large city on the average climatic conditions in rural area.

Table 1. Climatic Comparison Urban vs Rural

Pollution: Combustion Nuclei	Change Compared to Rural Area
SO_2	about 15 times more
CO_2	about 5 times more
CO	about 10 times more
Smoke	several 100 percent more
Temperature:	
Annual mean:	+1 to +1.5 F
Winter minimum:	+2 to +3 F
Wind Speed:	
Mean	-25 percent
Extremes	-20 percent
Calms	+5 to +20 percent

Hand (15) on comparing downtown Boston with the Blue Hill Observatory ten miles to the south-southwest determined that the city received approximately eighteen percent less insolation than Blue Hill.

Neiburger (25) on comparing contaminants from combustion of coal, oil and natural gas in industrial boiler (in lbs/10 BTU): Sulfur dioxide, coal-24.4, oil 17.5, and natural gas 0.02, we see the more smoke producing fuels produce more sulfur dioxide. It appears to be logical to assume that an increase or decrease of smoke should be proportional to an increase or decrease of sulfur dioxide.

The thermal structure, both vertical and horizontal, were studied by Duckworth and Sandberg (10) in three urban communities in California near San Francisco. Their study showed not only that large temperature

gradients occurred at night between open and urban area, but also that this temperature effect frequently caused instability up to about three times the roof height. The study, which included San Jose and Palo Alto, California, also related the magnitude of this heating effect to the size of the city; the more developed the city, the more it modified its atmosphere; thus, according to this study the larger the city, the less likely for it to have surface inversions. This conclusion was based on three criteria.

1. The least distance in miles along which a 1F temperature change was observed, based on measurements from the island center,

2. The amount of contiguous area, in square miles, enclosed by the isotherm that was plus 2 F greater than the mean for the city, as based on maximum and minimum temperatures,

3. The difference between the maximum and minimum temperatures recorded in the observed areas.

Baulch (3) investigated sulfur dioxide concentrations and their relation to the flucuation of wind directions. He found the more variable wind directions resulted in smaller sulfur dioxide concentrations.

DeMarrais (9) in examining the vertical temperature changes over urban areas and open country, discoverdd a great difference between the two. Unpopulated areas show surface inversions almost nightly and superadiabatic lapse rates exist during the clear daylight hours. The urban data other than being superadiabatic during

daylight hours showed no other general feature. Nocturnal inversions rarely occurred from 60 to 524 feet. He made no attempt to correlate tower data with pollutant concentrations.

Using the following assumption: that ventilation accomplished only by wind, a square city, an inversion limiting vertical escape of gas, a pollutant source over the entire area, an emission mixed immediately after release into the cities volume atmosphere, Smith (28) derived the formula $\chi_e = QS/\bar{u}h$ as an aid to determine the order of magnitude of pollutant concentration equilibrium where time is large. S is equal to the side of city (kilometers), t is time (seconds), $\bar{u}$ the mean windspeed (meters/second), h the height of the inversion (meters), χ_e the pollutant concentration (grams/cubic meter). He further determined the time required to achieve ninety percent of χ_e is given by $t_{90} = 2.3(S/\bar{u})$.

STUDIES OF ST. LOUIS

St. Louis has been aware of its pollution problem as early as the late 1800's. The first major step toward control of pollution came with the enactment of the Smoke Abatement Legislation in 1939. St. Louis was one of the few cities, out of twenty-four listed, that showed an increase in visibility during the time of the study period (19). The years compared were 1930 to 1938 inclusive versus 1958 to 1960 inclusive.

This points to the beneficial results from the legislation. It was estimated the smoke was reduced by seventy-five percent.

Schueneman (27) discussing the results of a 1936-37 and 1950 study of sulfur dioxide concentration in St. Louis noted an average reduction of 83 percent during the winter months. Schueneman observe.

> "...wind velocity does not affect sulfur dioxide concentrations to any extent during the summer but during the winter there is a decided trend towards lower concentrations with higher wind velocities."

Murino (24) attempted to correlate the sulfur dioxide concentration measured at a single station with various weather parameters, measured in the neighboring vicinity. He found seasonal and diurnal variations of sulfur dioxide amounts, variations with wind directions, with wind velocities, variations with pressure and humidity, variations with temperature and precipitation amounts.

Barnum (2) attempted to correlate single station COH values with rain, wind direction, pressure, specific humidity and temporal changes in the forementioned parameters. Results were disappointing, but this author feels the primary problem was the location of the sampler. It was located in the center of the heaviest polluted area and thus variations due to the wind direction, etc., would be slight. Hebley (16) also

concurred with this,

> "The condition of concentrations of impurities in the center of an industrial or emittance area is more or less constant no matter how the wind changes its direction."

Temporal changes yielded very poor correlations also. Although Barnum was sampling particulate matter (COH), this author concluded earlier, sulfur dioxide should be directly related to the amount of smoke produced.

The mesometeorological circulation in the Mississippi River Bottoms (Cahokia Bottoms) was examined by Arnold (1). He instrumented the WEW Radio Tower with three anemometers located 15, 110, and 220 feet above the ground. Also, a Gelman Automatic Phototape Sampler Recorder was situated 15 feet above the ground. The WEW tower is six and one-half miles slightly south of due east from the KMOX TV Tower. WEW is located at the intersection of Bunkum Road and Harding ditch. Among Arnold's findings were;

1. Wind at the WEW tower site varied from the winds of the Weather Bureau at Lambert Field forty-four percent of the time at night and thirty-four percent by day.

2. The temperature at WEW varied from downtown temperature, recorded on top of the United States Court and Custom House Building, a mean of -7 F to a maximum of -15 F on nights with calm or light wind conditions. The convection associated with the large

temperature differential resulted in a flow towards the "cities' heat island".

3. Inversions were quite common in the Bottoms. During the period studied, inversions of 5° or more occurred almost two-thirds of the mornings with the great magnitude of 27 F. Eighty percent of the inversion magnitudes were below the tops of the surrounding hills having 600 feet elevations.

4. An unexpected finding showed that most smoke particulate matter, collected at the WLW site, came under southwesterly circulation, i.e. not from the direction of the maximum emittance. This indicated a counterflow under the inversien.

STATEMENT OF PROBLEM

How do the temperature lapse rates; determined from temperature-differences, measured at three levels on an instrumented KMOX TV Tower in downtown St. Louis (located at 13th and Cole Streets); and winds observed at the Tower and three other locations in the metropolitan area, relate to the twenty-four hour sulfur dioxide concentrations sampled at twenty sites in the metropolitan area?

CHAPTER II

THE DATA

THE SULFUR DIOXIDE DATA

The United States Public Health Service, in cooperation with local agencies, is conducting an extensive air pollution study in the St. Louis-East St. Louis Metropolitan Area. The sulfur dioxide data from the multi-station sampling network used in this study were collected during the period December, 1963 through February, 1964. The aerometric data from this sampling network will provide a reliable scientific means of computing specific ambient pollution concentration based on diffusion related to known source emissions* and given meteorological parameters (11). These data will also provide basic information to assist in establishing sulfur dioxide air quality standards in the future and to aid in air resource management activities.

SAMPLING SITES AND SAMPLING PERIODS

Ambient concentrations of any air pollutant is a consequence of source emission strength and the dispersion capability of the atmosphere. It was therefore,

* The Sulfur Dioxide emission inventory is being collected at this time.

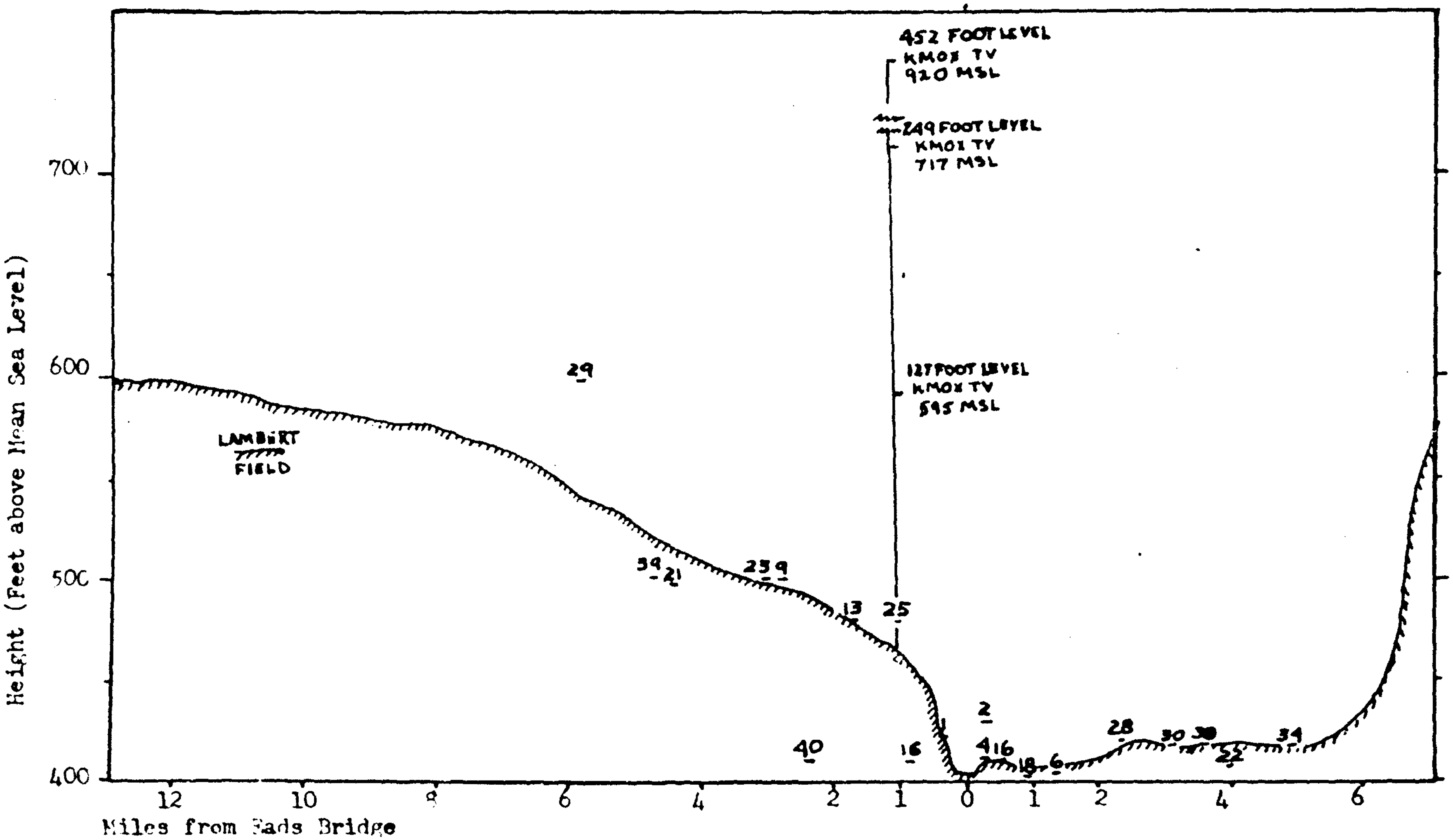


Figure 3. East-West Topographic cross secti n through Eads Bridge.
Sulfur Dicxide sites elevation (MSL).

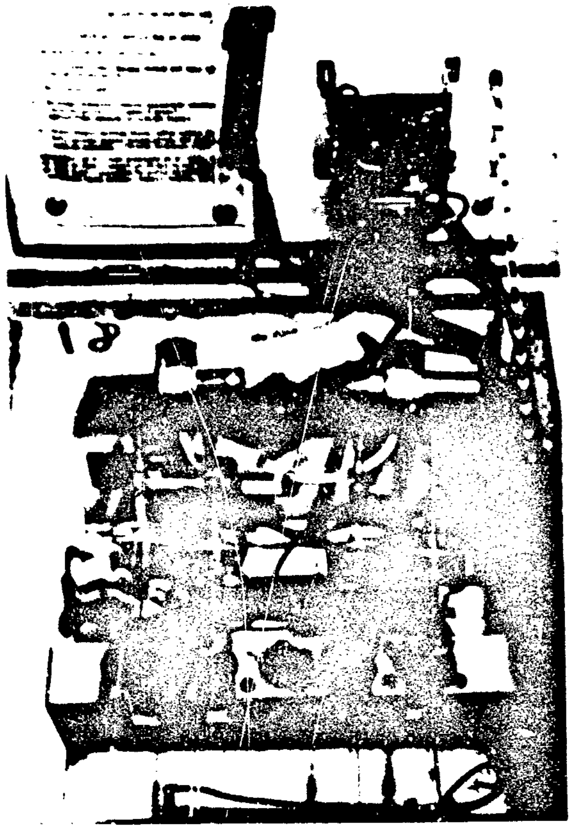


Figure 4a. Sulfur dioxide sampler.

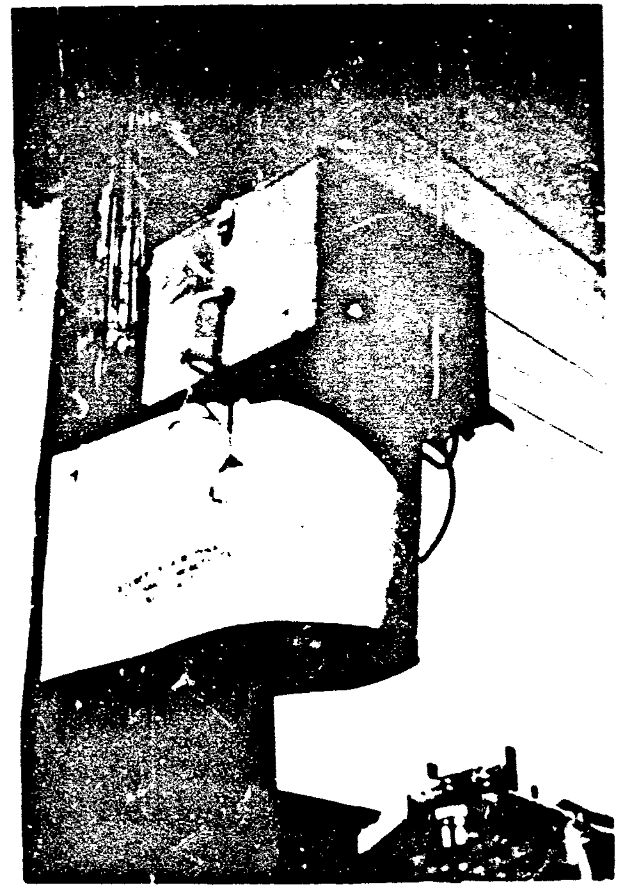


Figure 4b. Typical sulfur dioxide sampler installation.

deemed desirable to measure ambient concentration of sulfur dioxide during the season of relative maximum concentration; a compromise of highest emission at the source and greatest atmospheric stability.

The sampling operation was cycled on the basis of a pollution day. The sampling time began and ended at 1400 local time each day. The concentration of sulfur dioxide is in the middle of the usual daily interval of low concentration at this time (24)(27). This allows the sampling cycle to run from daily low concentration to daily low concentration, thereby reducing the chance of changing collection bubblers on the instrument in the middle of the diurnal concentration peak. A total of 1,429 twenty-four hour samples were taken and analyzed during the December, 1963 to February, 1964 operations. The geographical locations and area classification of the twenty stations operated during the 1963-64 sampling season, are included in Appendix A, elevations are shown in figure 3.

SULFUR DIOXIDE GAS SAMPLER

A twenty-four hour gas sampler was located at each of twenty sampling sites, figure 4a and 4b. The sampling units were mounted on utility poles at approximately 10 feet above ground level. This was high enough to discourage tampering, yet low enough to be

safely accessible for daily servicing. Electric power was provided, for the vacuum pump, through a grounded thirty ampere circuit breaker box mounted on the pole. The circuit breaker was connected to the pole's secondary electrical lines. The samplers were essentially the basic sampling unit employed in the National Air Sampling Network Gas Sampling Program (26) modified to sample for a single gaseous air pollutant. The sampler consists of a bubbler collection unit and an external vacuum pump, that operated twenty-four hours a day, to move the sampled air through the collector. The gas passes through the bubbler and a critical connecting orifice to the vacuum pump. The critical connecting orifice, a 27-guage, 5/8 inch hypodermic needle, was selected; it delivered a maximum flow of 190 to 210 milliliters per minute at an operation vacuum of 20 inches of mercury or better. The total volume of air sampled by a bubbler was approximately 290 liters. The critical airflow through each needle was measured against a calibrated flowmeter before and after each sample was collected. The maximum allowable flow rate reduction was ten percent. Under similar sampling conditions in Nashville, Stalker et al (30) estimated a ±10 percent experimental error for the determination of free atmospheric sulfur dioxide. The calibrated flow rate, before and after sampling, was recorded.

Sample loses resulted from varying reasons: malfunction of vacuum pump, tampering by in[illegible]ders and

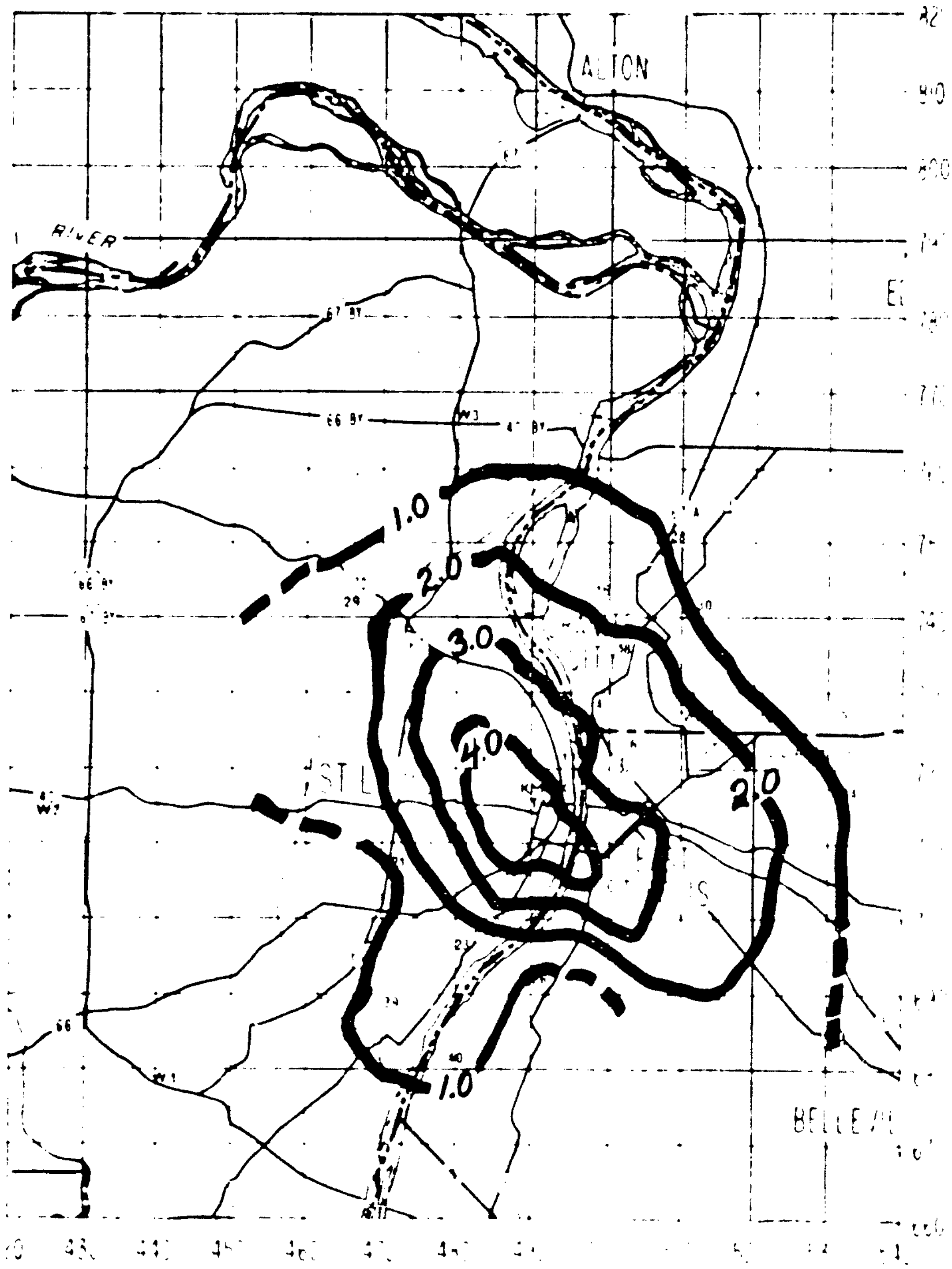


Figure 5. Twenty-four hour sulfur dioxide concentrations in PPHM.
Isopleths of definite values
Isopleths of probable values
Isopleth values from median values for 20 locations from December 1, 1963 to February 29, 1964.

freezing of moisture in sampler lines. The ambient air temperature varied from a low of -6 F to 70 F. Freezing was avoided by mounting two 30 watt resistance type heaters in the sampler. These thermostatically controlled elements maintained an average temperature of 75 F in the samplers.

The sampler employs the chemical absorption principle, using selective liquid reagent filled bubblers. Sulfur dioxide is stripped from the sampled air stream by the complex action of sodium tetrachloromecurate absorbing reagent.

ANALYSIS

The collected samples were sent daily to the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio for analysis. The analytical method used was that of West and Gaeke (36) as modified for the Auto-analyzer by Welch and Terry (35). The results were reported in microgram per cubic meter and parts per hundred million. The twenty-four hour median values for twenty sites are indicated in figure 5.

KMOX TV TOWER INSTRUMENTATION

The KMOX TV Tower is located in the commercial and industrial district of St. Louis, 13th and Cole Street, centrally located with respect to the metropolitan area. It is located on the KMOX TV Studios

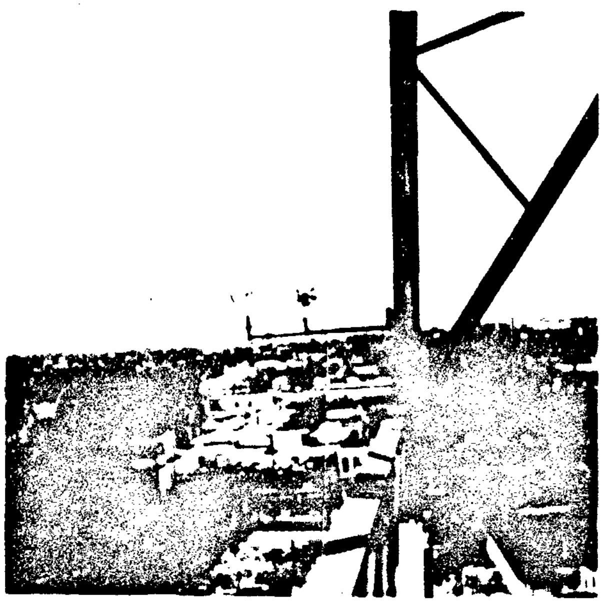


Figure 6. 6 Bladed Aerovane anemometer - Looking North from the 127 foot tower level.

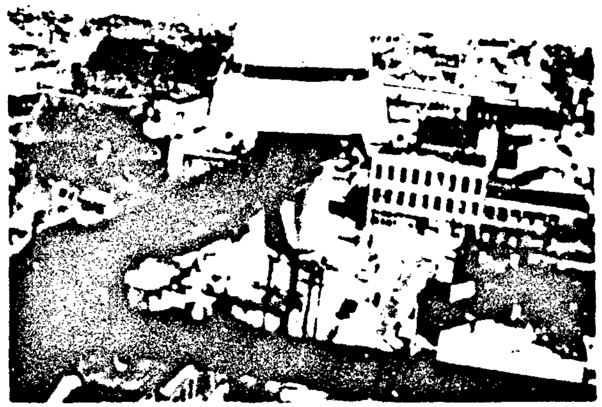


Figure 7. Aspirated Thermohm unit - Looking North from the 127 foot tower level.

Figure 8. View of the tower base, looking West from 12th and Cole Street.

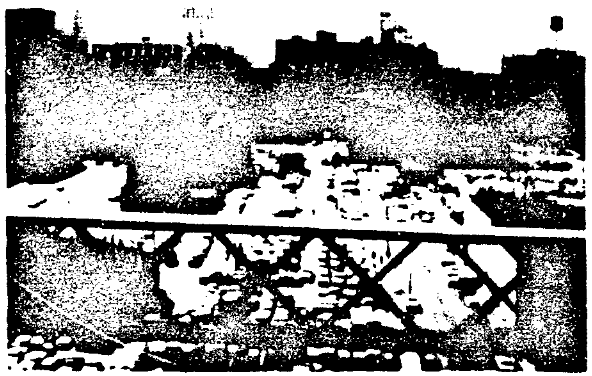


Figure 9. Looking South from the 127 foot Tower level.

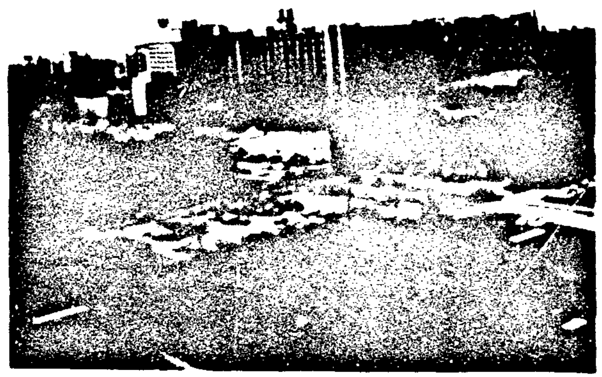


Figure 10. Looking South-west from the 127 foot Tower level.

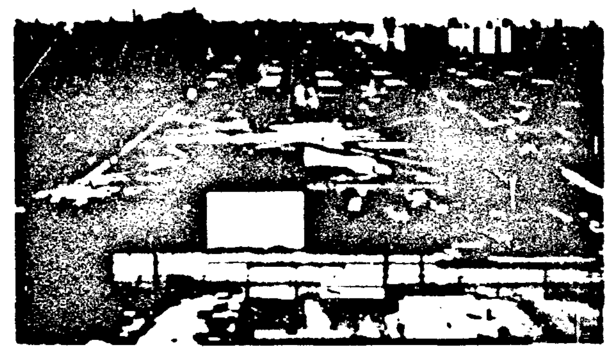


Figure 11. Looking West from the 127 foot Tower level.

Figure 12. Looking North-east from the 127 foot tower level.

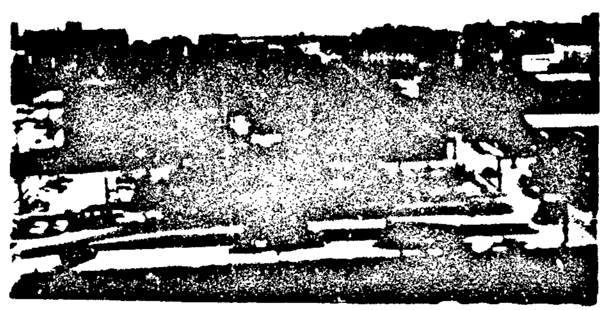


Figure 13. Looking East from the 127 foot tower level.

Figure 14. Looking Southeast from the 127 foot tower level.

(height 38 feet) which has a roof of tar and brown gravel (figure 8). To the north and to the east of the tower is an asphalt parking lot.

The tower is instrumented with two wind recording systems and a vertical-temperature-difference measuring system. The instruments were installed in the spring of 1963. They are attached to the northwest corner of the tower. Exposure of the tower to atmospheric flow is good except for the southeast quadrant. Adjacent roofs are approximately 80 feet below the 127 foot tower level. To the southeast the Post Dispatch Building rises to approximately 60 feet above the street level. Beyond that buildings gradually increase in height (figures 7, 8, 9, 10, 11, 12, 13, 14).

TEMPERATURE-DIFFERENCE INSTRUMENTS

The temperature-difference measuring system is a Leeds and Northrup unit (34). It consists of three shielded, aspirated thermohm units connected to a Speedomax Type G recorder by means of a mineral insulated cable. The aspirated thermohm units are located: 127 feet above the street level (468 feet above the mean sea level), 249 feet above the street, and 452 feet above the street. The recorder is located in the basement of the studio building.

The temperature sensing element is a Leeds and Northrup Thermohm Detector Type 8195-B 10 (34). The

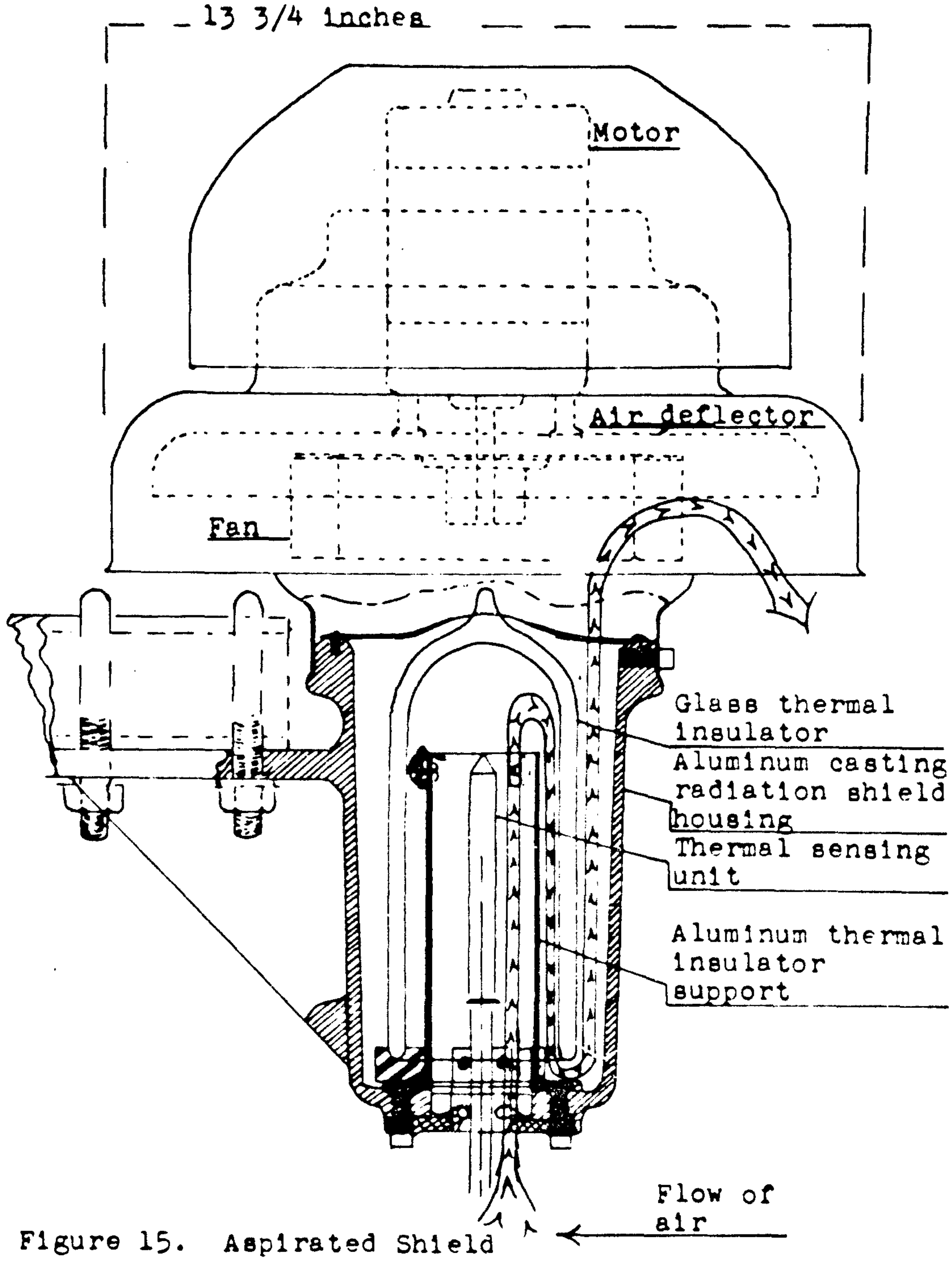


Figure 15. Aspirated Shield

element is a copper wire resistor, having 100 ohms resistance at 77 F. The response time is 40 seconds, i.e. 90 percent of temperature change in stirred water moving approximately one foot per second occurs within 40 seconds. Limit of error is $\pm$0.5 F from 100 to 250 F. The copper wire resistor is encased in a drawn brass tube 15/32 inches outside diameter and 4 3/8 inches long.

The aspirated thermal shield (figure 15) protects the sensing element from sensing thermal conditions other than ambient air. There has been a gradual deterioration on the paint since installation. No attempt has been made to determine the magnitude of this effect. But it is felt it should fall within the error limit of the sensing elements since the primary purpose is determining the temperature difference and the elements' shield paint would deteriorate at the same rate, hence causing little error.

The recorder is a Leeds and Northrup Speedomax Type G (34). It records the temperature-difference between the 127 foot element and the 249 foot element; the 127 foot element and the 452 foot element. The chart speed is three inches per hour. The temperature-differences are recorded every five minutes in tenths of a degree Fahrenheit. The recording element cycles and moves across the chart so as to print a number (1 to 3)

and beside the number a dot that records the temperature-difference for each layer. The traces are then reduced to average hourly values by the equi-area method described in the wind section.

The temperature sensing elements are calibrated by immersing each one in a stirred ice bath. The maximum temperature spread allowed is ±0.1 F between Leeds and Northrup recorder and a mercury-in-glass thermometer (graduated in tenths of a degree Fahrenheit).

WIND INSTRUMENTS

The three Bendix Friez wind transmitters (Model 120) are located 127 feet, 250 feet, and 459 feet above the street. These are each individually connected to Aerovane recorders located in the building basement.

The windspeed is measured by a six-bladed impeller fastened to the armature of a tachometer magneto. The start speed of the impeller is 1 3/4 MPH and the chart is set to read 1 3/4 MPH when wind is calm. The speed of rotation of the impeller (rotor) is directly proportional to the speed of the wind striking the blades; the voltage generated by the magneto is a function of the wind speed. The speed of the wind is marked by the recorder.

Wind direction is measured by a streamlined vane which is coupled to the rotor of a type 1 HG Synchro. This synchro electrically transmitts the position of

the vane to a 1 F synchro in the recorder; the angular displacements are measured, transmitted and recorded.

The wind direction and wind speed were fed into an Aerovane Recorder. There was a recorder for each anemometer. Inked traces of wind speed and wind direction were simultaneously produced on a continuous paper chart by the two-channel recorder. The recorder has a wind speed range of 0 to 100 MPH recorded on the right channel. Direction data from 0 to 360 degrees is recorded on the left channel. The chart drive rate is three inches per hour.

WIND DATA

The wind observing stations consist of the two anemometers at KMOX TV Tower and one at each of the following: Lindbergh High School, twelve miles southwest of the KMOX TV Tower (W 1 on area map); Missouri State Highway Patrol Station, thirteen and one half miles west of the TV Tower (W 2 on area map); and Hazelwood High School, nine and one quarter miles from the TV Tower (W 3 on area map). The anemometers are located approximately fifty feet above ground level. The wind equipment is the same as on the TV Tower. At each of the outlying stations relative humidity and temperature are also recorded on Belfort Instrument Corporation hygrothermographs.

The wind data charts were reduced to average hourly wind direction and wind speed at the Taft Sanitary Engineering Center, Cincinnati, Ohio. An equi-area method was used. A cursor line was placed on the direction and wind-speed lines so that there was an equal area between the divided data lines and the cursor line. This was done on a specially built machine, "Oscar Jay." The machine automatically recorded the data on machine punch cards. The hourly data were recorded in miles per hour for speed and in whole degrees for direction.

CHAPTER III

ANALYSIS OF DATA

POLLUTION ROSES

The use of a pollution rose in relating the wind field to pollution concentrations and pollution sources, is common (7). Pollution roses were computed for the stations described in aerometric section. Refer to Appendix B for format.

The pollution rose used in this study consists of a tabulation of wind direction at the aerometric stations and concentration categories for the sulfur dioxide sampling sites. An average concentration for each direction interval was calculated. The concentrations (microgram per cubic meter) are added for all observations of each of the sixteen principal directions of the compass. These concentrations for each direction are then divided by the number of observations for each direction, yielding the average concentration-direction. Since we are dealing with twenty-four hour concentrations, it is felt that this is as meaningful an analysis as can be made.

A tabulation of the four maximum average concentration-directions for each station and site are shown in Table 2. The sites are grouped according to their mean sea level. It was then determined whether the concentration fell within one direction interval of the

TABLE 2
FOUR MAXIMUM AVERAGE CONCENTRATION-DIRECTIONS
SULFUR DIOXIDE SITE-WIND STATION
400 TO 449 FEET MSL.

1-1		1-2		1-3		1-4		1-5	
SW	8.465	S	8.171	SSE	9.605	SSE	8.655	SW	9.165
SSW	7.820	SW	7.391	SSW	8.420	S	7.285	SSW	7.431
SE	7.743	SSW	7.137	SW	7.643	SE	7.273	S	6.756
WSW	7.517	SSE	6.859	WSW	7.496	SW	6.975	SSE	6.347
2-1		2-2	(1)	2-3		2-4		2-5	(2)
W	8.166	W	7.371	W	8.617	WSW	9.455	WSW	9.592
WNW	5.774	WNW	7.170	WNW	6.983	W	5.613	W	5.711
WSW	4.754	WSW	5.354	WSW	5.004	SW	4.865	ENE	5.409
SSW	3.599	NE	4.111	SW	4.747	SSW	4.015	NE	5.102
4-1		4-2		4-3		4-4		4-5	
SW	9.360	SW	8.766	SSW	9.142	SW	8.588	SW	9.912
SSW	8.533	SSW	8.058	WSW	9.084	SSW	8.599	SSW	8.815
WSW	7.815	WSW	7.054	SW	8.683	S	8.024	CLM	7.166
CLM	6.130	CLM	6.447	CLM	6.628	CLM	5.242	WSW	6.215
6-1	1	6-2		6-3	(1)	6-4		6-5	
WNW	5.006	NW	5.007	WSW	5.561	W	6.025	W	5.822
WSW	4.944	WNW	5.005	WNW	5.556	SW	4.762	WNW	5.698
CLM	4.827	WSW	4.876	W	4.738	WNW	4.696	SW	4.948
NW	4.605	SW	4.430	ESE	4.529	SSW	4.598	WSW	4.592
16-1		16-2		16-3		16-4		16-5	(1)
SW	4.401	SSW	3.838	SSW	3.996	S	3.793	SW	3.982
SSW	4.026	SW	3.368	SW	3.728	SW	3.376	SSW	3.613
S	3.178	S	2.987	S	3.012	SSW	2.942	S	3.429
WSW	3.116	SSE	2.597	WSW	2.764	SSE	2.317	ESE	2.900
18-1		18-2		18-3		18-4		18-5	(1)
SW	5.385	SW	5.958	SW	5.759	SSW	5.691	CLM	6.375
WSW	5.210	CLM	5.614	SSW	5.753	S	5.363	SW	6.077
SSW	5.204	SSW	4.936	WSW	5.340	SW	5.207	SSW	5.867
CLM	5.089	WSW	4.888	CLM	5.176	CLM	4.293	E	5.152
22-1		22-2		22-3	(1)	22-4		22-5	
WSW	4.551	CLM	5.760	WSW	5.766	SW	4.531	SW	5.340
W	4.504	WSW	5.000	SW	4.979	SSW	4.234	CLM	5.041
SW	4.255	SW	4.755	ESE	4.641	W	4.225	WSW	4.771
CLM	4.244	W	4.358	W	4.628	CLM	4.098	W	4.577
26-1	(1)	26-2		26-3		26-4		26-5	
NNE	4.309	NE	3.505	N	3.896	N	3.385	NNE	4.215
N	4.001	NNE	3.434	NNE	3.735	NNE	3.097	NE	4.184
ESE	2.870	N	3.434	NNW	2.732	NNW	2.809	ENE	3.624
NNW	2.278	ENE	2.646	NE	2.642	NW	2.766	N	3.519
28-1		28-2		28-3		28-4		28-5	
SW	4.827	SW	4.307	SSW	4.554	SW	4.634	SW	4.982
SSW	4.194	SSW	3.986	SW	4.488	SSW	4.039	SSW	4.393
WSW	3.768	S	3.422	WSW	4.047	S	3.936	S	3.340
S	3.053	WSW	3.354	S	3.314	SSE	2.519	SSE	2.976
30-1	(1)	30-2		30-3		30-4		30-5	(1)
SW	2.401	SW	1.951	SSW	2.433	SW	2.417	SW	2.720
WSW	2.133	SSW	1.797	SW	2.075	SSW	1.615	SSW	2.287
SSW	1.618	WSW	1.723	WSW	2.424	WSW	1.563	WSW	1.672
N	1.477	S	1.398	S	1.527	S	1.422	NNE	1.473

TABLE 2 CONTINUED

400 TO 449 FEET MSL CONTINUED

34-1	(1)	34-2		34-3		34-4		34-5	(1)
W	2.369	WSW	2.488	WSW	2.607	W	2.480	W	2.398
CLM	2.011	W	2.094	SW	2.379	WSW	2.072	WSW	2.377
WSW	1.997	SW	2.090	WNW	2.363	SW	2.006	WNW	2.262
WNW	1.895	WNW	2.011	W	2.340	SSW	1.988	SSE	2.152
38-1	(1)	38-2		38-3	(1)	38-4		38-5	
NNE	5.481	NE	5.956	N	5.141	NW	4.736	NE	5.651
N	4.103	N	4.927	NNE	4.222	NNE	5.050	ENE	5.391
CLM	4.101	ENE	4.135	NNW	4.101	N	4.736	N	5.112
ENE	3.779	NNW	3.914	CLM	4.154	NNW	4.416	NNW	5.047
40-1		40-2		40-3		40-4		40-5	(1)
W	2.650	NE	3.713	W	3.019	NNE	2.732	NE	3.454
NNE	2.573	W	2.851	NE	2.881	WSW	2.730	ENE	3.069
N	2.524	ENE	2.704	WSW	2.727	SW	2.559	W	2.588
ENE	2.458	WSW	2.528	SW	2.611	NE	2.164	CLM	2.388

450-499 FEET MSL

13-1		13-2		13-3		13-4		13-5	(1)
ESE	9.409	NE	8.444	E	8.319	ENE	7.921	ENE	10.478
SW	8.563	ENE	7.891	SSW	8.080	S	7.371	NE	10.270
NNE	5.888	E	7.892	ENE	7.500	NNE	7.114	E	10.066
SSW	7.907	SW	7.822	NNE	7.336	SSW	6.933	ESE	8.684
25-1	(1)	25-2		25-3		25-4		25-5	
S	4.016	S	3.790	WSW	3.719	S	4.017	SSE	4.394
SSW	3.992	SSW	3.769	SSE	3.584	SSE	4.017	S	4.102
CLM	3.559	SSE	3.605	S	3.535	SSW	3.441	SW	3.841
SW	3.525	SW	3.517	SW	3.466	SW	3.273	SSW	3.034

500-549 FEET MSL

9-1		9-2	(1)	9-3		9-4	(1)	9-5	
ESE	11.251	SSE	9.593	ESE	10.117	E	9.299	ESE	12.037
SE	9.338	SE	8.707	E	9.709	S	8.790	E	10.812
SSE	9.264	E	8.657	SSE	9.529	SF	8.900	SW	10.374
SW	9.055	ENE	8.411	WSW	9.420	ESE	8.517	ENE	9.531
21-1	(1)	21-2		21-3		21-4		21-5	
ESE	6.379	E	4.959	E	5.412	ENE	5.198	E	6.202
E	4.621	ENE	4.173	ENE	5.061	E	4.356	NE	5.774
NNE	4.602	NE	3.925	NE	4.245	NE	3.749	ENE	5.544
SSW	3.637	ESE	3.595	N	3.595	NNE	3.360	NNE	4.426
23-1		23-2		23-3		23-4		23-5	
ESE	7.052	E	7.409	ENE	7.841	ENE	6.923	E	7.331
E	6.784	NE	5.982	E	7.492	NF	5.741	NE	6.861
NNE	6.080	ENE	5.392	NE	6.337	E	5.597	ENE	6.340
N	5.594	ESE	5.256	NNE	5.924	NNE	4.974	ESE	6.157
39-1	(1)	39-2		39-3		39-4		39-5	
SW	5.766	SSW	5.306	SSW	5.161	S	4.939	SW	5.225
SSW	5.294	SW	4.767	ENE	4.331	WSW	4.716	E	4.937
CLM	4.708	ENE	4.440	E	4.250	ENE	3.962	S	4.900
E	4.628	S	4.283	SW	4.074	SSW	3.920	SSW	4.766

ABOVE 600 FEET MSL

29-1		29-2		29-3	(1)	29-4		29-5	
CLM	7.364	SE	5.917	SE	6.793	ESE	7.351	CLM	7.666
SE	7.228	SSE	5.813	SSE	5.634	SE	6.540	SE	6.109
SSE	5.950	S	5.502	S	5.155	SSE	5.469	SSE	5.850
S	5.832	CLM	4.833	NE	5.046	CLM	5.023	S	5.164

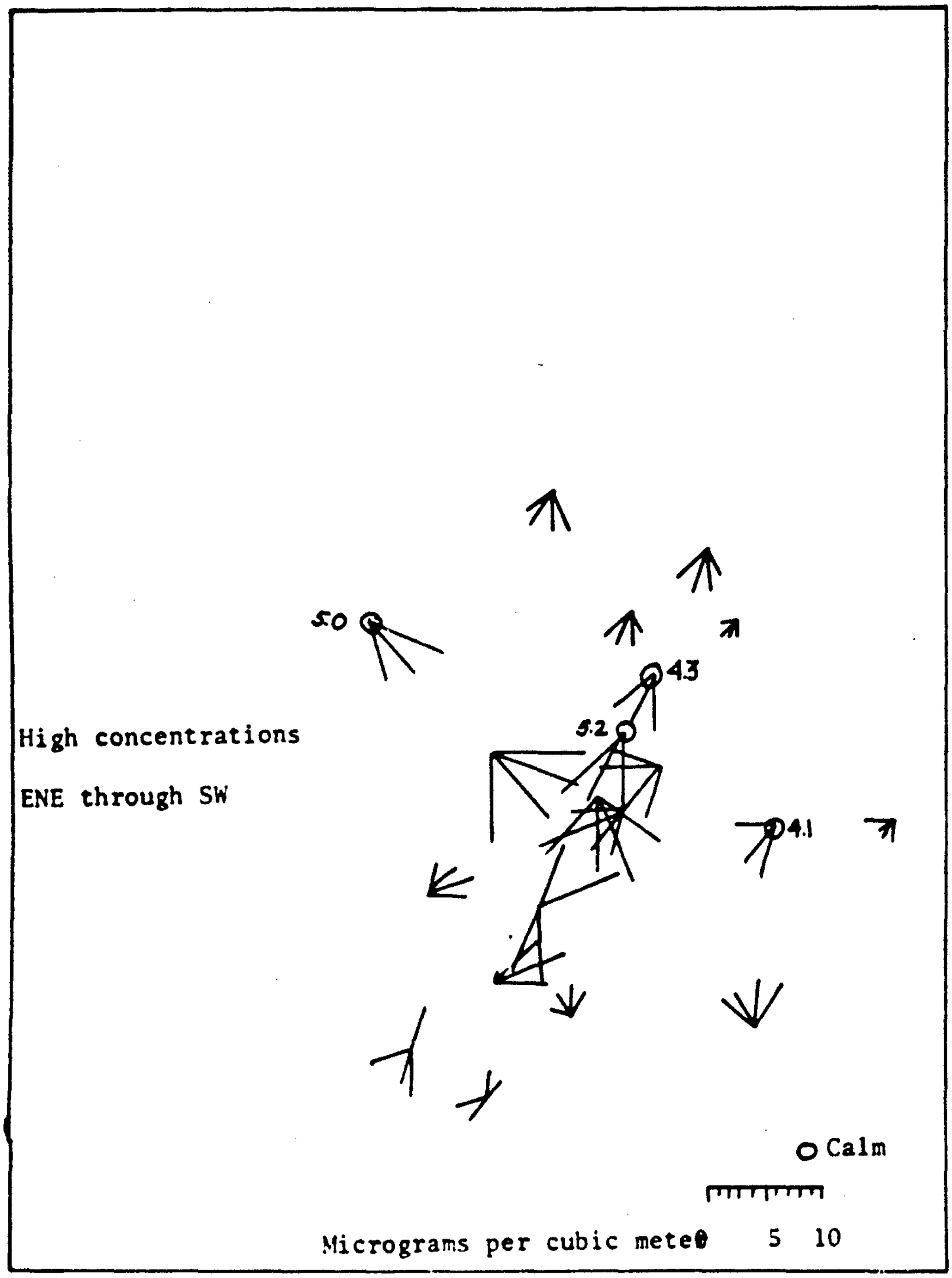
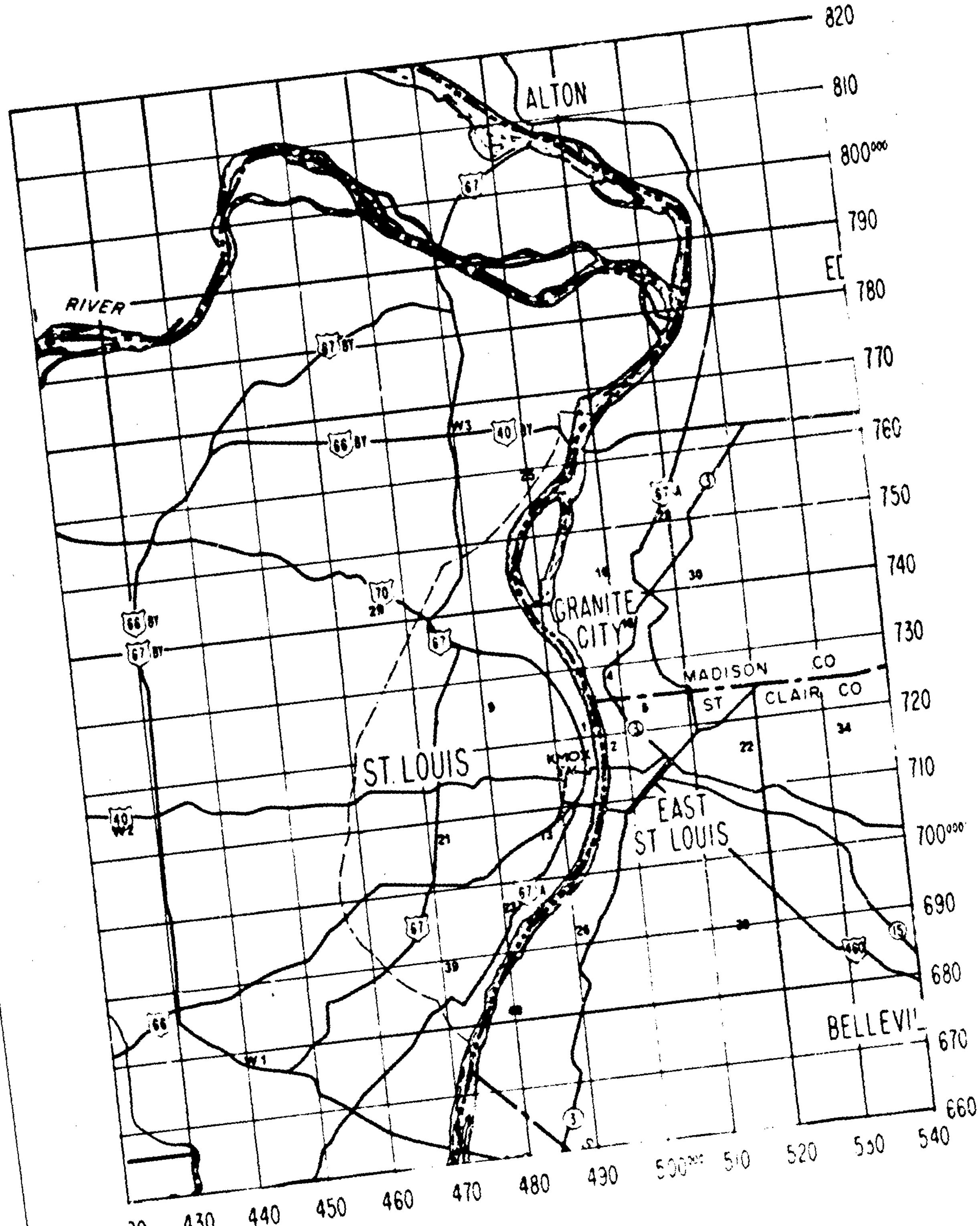


Figure 16. The four highest direction-concentrations for each sulfur dioxide site.


ALTON
RIVER
GRANITE CITY
MADISON CO
ST CLAIR CO
ST. LOUIS
KMOX
EAST ST LOUIS
BELLEVI
820
810
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
430
440
450
460
470
480
490
500
510
520
530
540

concentration directions of other stations for a particular site. We see in Table 2, site 22, and wind station 3, (22-3) that one of the four highest maximums occurred; 4.641 micrograms per cubic meter, when the wind was blowing from the ESE. Looking at the data from the four other wind stations and site 22's concentrations, no two other maximums were reported in the intervals E, ESE, or SE. We then consider 22-3 a deviation. Deviations are listed in parenthesis to the right of site-station designator.

Sulfur dioxide Site 4 shows the best agreement between the five wind stations. Sites 38 and 34 have the greatest spread. Both of these latter sites are located near to the bluff which borders the Mississippi River flood plain on the east indicating a possible topographical effect.

Wind station 4 shows the least number of deviations, of the five wind stations for all sites.

The four highest concentration-direction vectors of wind station 4 were plotted on an area map (figure 16). The vectors extend in the direction from which the wind is blowing. The vector length is proportional to the sulfur dioxide concentration (micrograms per cubic meter).

The majority of the site vectors point in toward the general sector center of the metropolitan St. Louis business and industrial complex. This is a typical pattern for a metropolitan area (37). Sites 23, 39, and 40

indicate sulfur dioxide source to the south and west of their location. The pollution rose for Site 9 indicate relatively high concentrations from the northeast, going clockwise, through the west-southwest. This site is located in a residential area where coal is used as a domestic heating fuel. There is also some heavy industry nearby. See Appendix A for site classifications. (11).

VERTICAL TEMPERATURE DIFFERENCES

The temperature lapse rates recorded on the KMOX TV Tower differ appreciably from the normal open country vertical thermal structure. The data show a greater frequency of unstable conditions. The TLL* appears to be most stable, with THL showing increased instability. Appendix D shows the hourly frequencies and percentages for each of five stability categories.

The temperature-differences were divided into five categories: superadiabatic, dry-adiabatic, lapse, isothermal and inversion. The dry-adiabatic lapse rate in the lower boundary of the atmosphere approximates 5.4 F per 1000 feet. Therefore:

TLL HT = 122 feet. Dry-adiabatic Lapse Rate = -0.0588 -0.6 TAL HT=325 feet. Dry-adiabatic Lapse Rate= -1.755 -1.8F THL HT=203 feet. Dry-adiabatic

* Defined in Convention and Symbols pp ix.

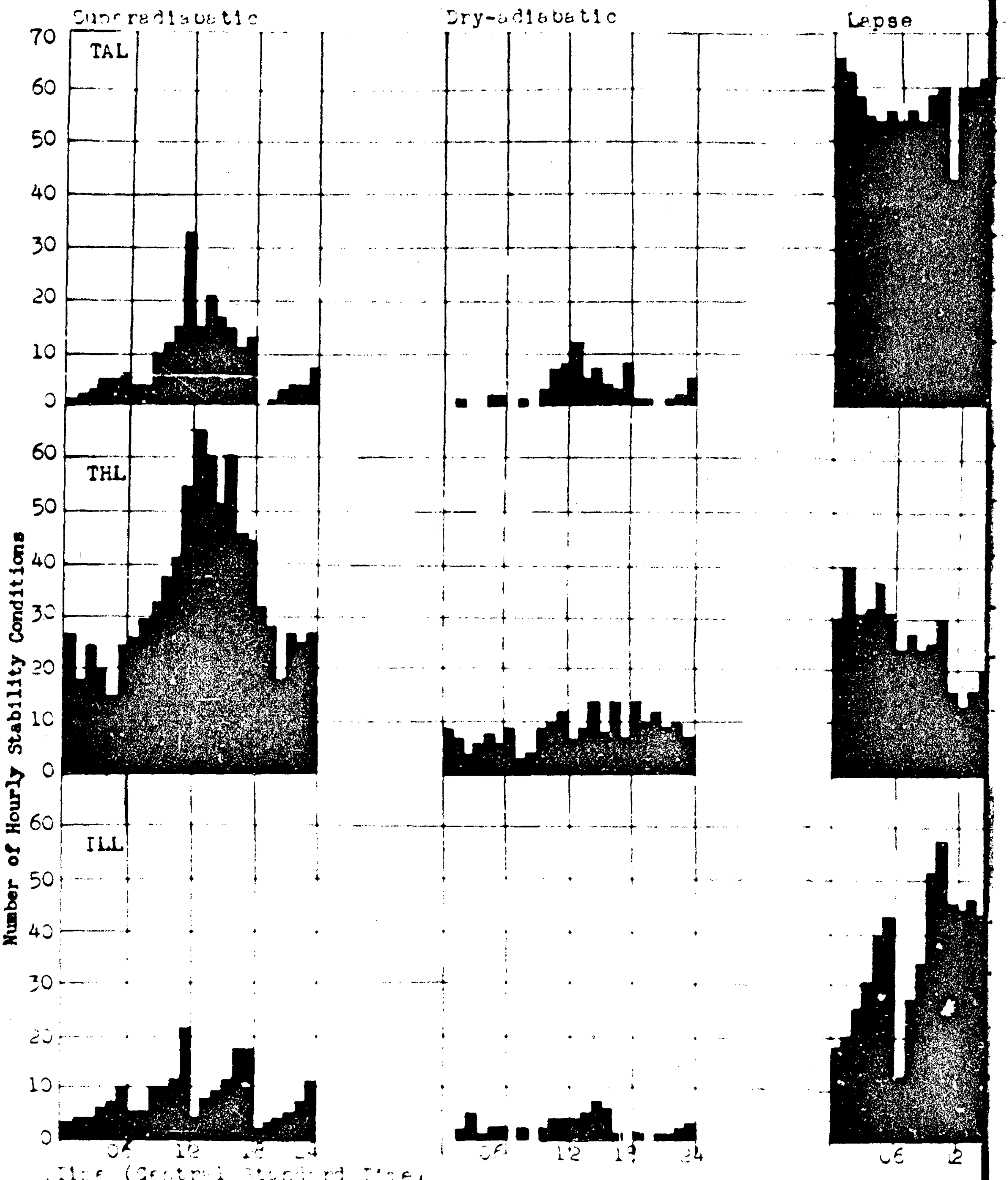
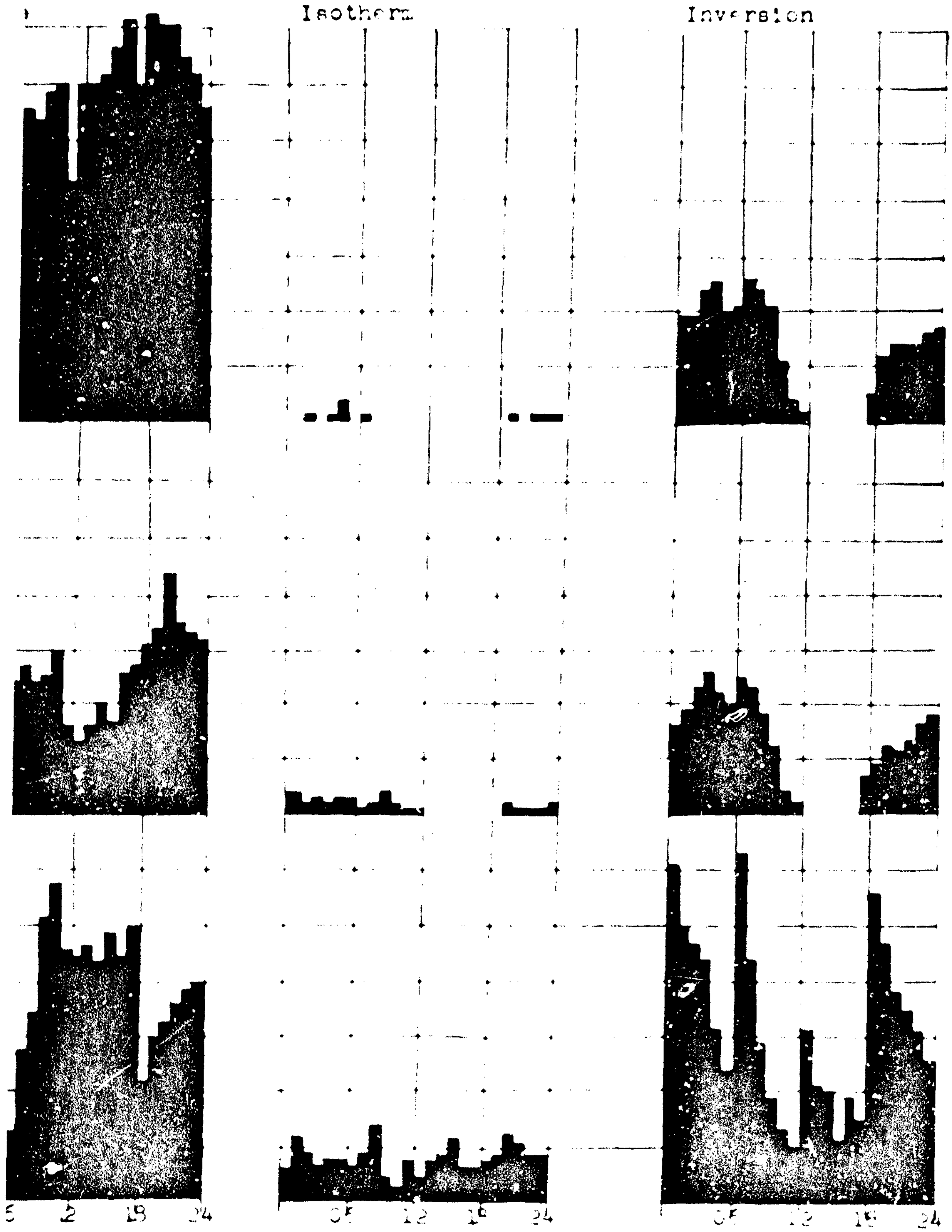


Figure 17. Hourly Frequency Graphs for each stability category.

A



B

Lapse Rate = -1.096 - 1.1F. The superadiabatic lapse rate is less than dry-adiabatic lapse rate. The lapse condition is greater than -0.7F and less than 0.0F. The isothermal lapse rate is equal to 0.0F and the inversion is greater than 0.0F.

Figure 17 shows the hourly frequencies for the stability categories. The requirement for a specific temperature difference for the dry-adiabatic and isothermal categories result in a lower frequency of occurrence.

There is in the TLL data an apparent six hourly cycle of frequencies in the superadiabatic and inversion categories. The superadiabatic builds up to peaks at 0600, 1200, 1700-1800, and 2400 local time then falls rapidly. The fluctuations in the inversion conditions have peaks occurring one hour later and decrease gradually. The major maxima of frequency of occurrences in these peaks occur when one would expect them; 1200 for the superadiabatic conditions and 0700 for the inversion conditions. This feature needs additional investigation.

The lapse conditions show an 0700 and 1400 trough, otherwise they are spread throughout the day with the maximum occurring during daylight hours.

THL instability is largely attributable to the presence of superadiabatic conditions, 40.9 percent of the time during daylight hours and the maximum of 66 occurrences at 1300. The superadiabatic conditions drop off sharply at 1600 and continue through the night

Table 3: Inversion or Superadiabatic Lapse Rate Durations Ten Hours or Longer

Superadiabatic

Day	Length (hours) [illegible]	[illegible]	[illegible]	Sky Cover Avg. (tenths)
December				
14			5	0
15			17	0
18-19			14	0
19-20			20	9
22-23			39	7
29-30			23	0
January				
25	17	17	(6)	0
26-27	37	15-16	11	2
February				
13			11	[illegible]
26			12	1

Inversion

Day	Length (hours) [illegible]	[illegible]	[illegible]	Sky Cover Avg. (tenths)
December				
3-4-5	41			8
6-7	36	19	18	2 [illegible]
7-8	33			10
9	10			8
2[illegible]-23	15			0
January				
4	1[illegible]			0
4-5-6	41	(J4-5) 13 [illegible] (Clr)	(J4-5) 16 [illegible] (Clr)	6
6-7	15	11	11	0 N
15-16	10	1[illegible]	12	0 M
17-18	12	18	19	0
20-21		15	15	0
29-30	10	17	16	2
February				
1-2	11	13	13	0
3-4	33			0
6-7	13			[illegible]
8-[illegible]	22			8
9-10	14			9
13-14	[illegible]			3
14-15	1[illegible]			3
22-23	16			5
24-25	13			4
27-28	15			5
29	13			0

*= [illegible]

averaging 22 occurrences for each night hour.

The THL dry-adiabatic conditions were dispersed over the twenty-four hour period with a maximum occurring late afternoon-early evening.

The THL lapse condition shows a maximum during the nocturnal period with an approximate average of thirty occurrences for each hour. Noticeable is a minimum number of occurrences during the superadiabatic maximum.

During night time an average of two hourly THL isothermal conditions occur over the sampling period with none during daylight hours. There also was an absence of inversions during daylight hours with a maximum frequency of twenty-six hours at 0400 and twenty-five times at 0700. The occurrences fall off sharply from 0800 to none at 1300.

The temperature differences over the TAL interval show the lapse to be the predominant condition. A slight maximum occurrence during the evening hours and a minimum during the period 0400 to 0900.

The TAL inversion category shows no occurrences from 1400 through 1800 with maximum occurrences at 0700. The frequency of occurrences drop off rapidly after 0900. Dry-adiabatic conditions have the same configuration with maximum frequencies during daylight hours.

Table 3 giving the durations of superadiabatic and inversion conditions also shows THL to be most unstable.

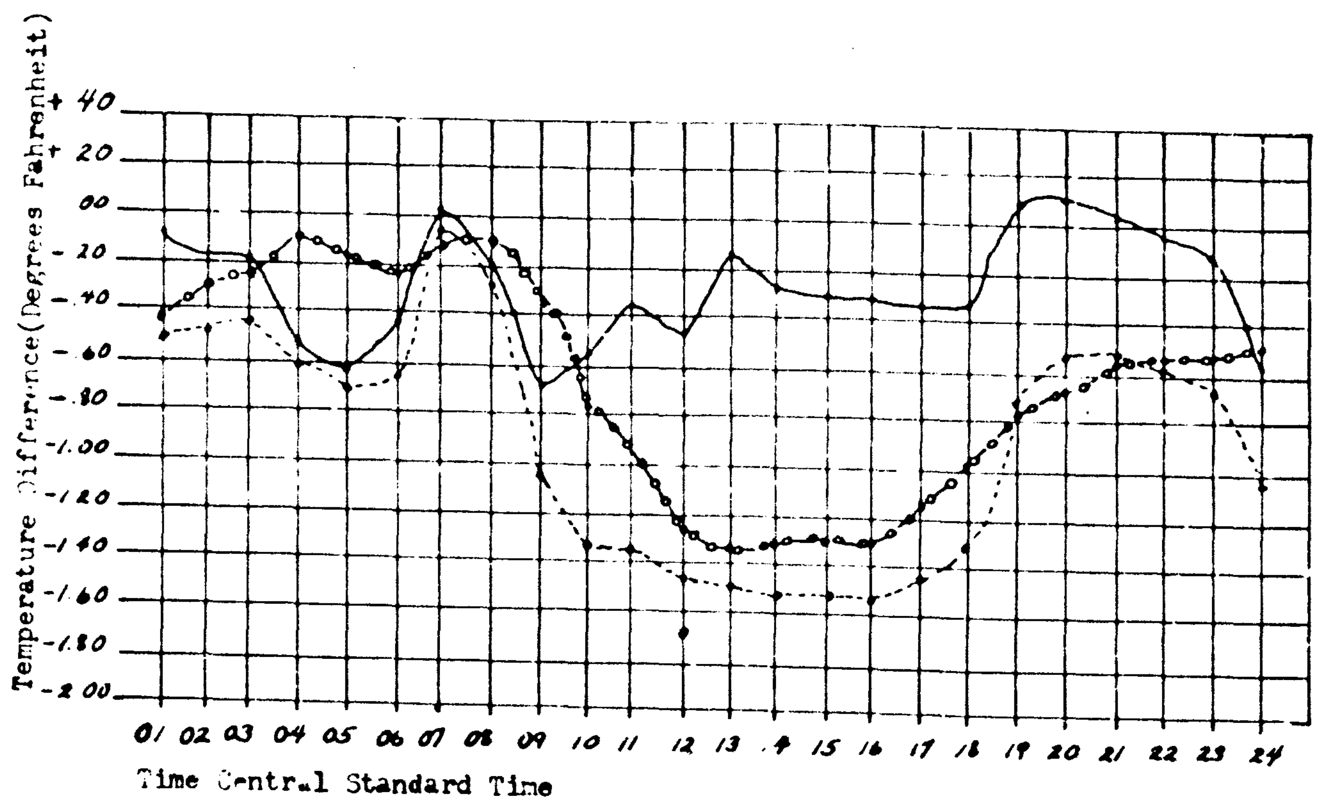


Figure 18. Average hourly temperature difference curves.
TLL ——— THL •—•—• TAL --------

AVERAGE HOURLY TEMPERATURE DIFFERENCES

The average hourly temperature difference curves for the KMOX TV Tower data are shown in figure 18. Four hourly observations were discarded as being in error because of extremely high values:

				Station 4	Station 5
11 December	0400	THL	19.4 F	059/10	064/15
28 December	1300	TLL	19.9 F	044/04	146/06
2 February	0600	TLL	19.4 F	096/06	MSG
13 February	1100	TLL	19.4 F	312/15	277/13

Possibly these were due to a smoke plume engulfing the thermohm unit. The wind direction was not the same in all cases, ruling out the smoke coming from one source.

The TLL curve and its reflection of the TAL curve does not portray a systematic progression of temperature-differences through the day. The maximum positive difference occurred at 2000 rather than at sunrise as one would expect.

The THL curve shows a normal hourly progression. From 0000 to 0700 increasing stability after sunrise increasing instability to a maximum at 1300 and gradual increase in stability thereafter.

The only conclusions one can draw from this are that there is increased instability in the THL compared to the TLL. Since TAL is an addition of TLL and THL, it represents a smoothing of the TLL curve by the THL. No specific relationship can be determined.

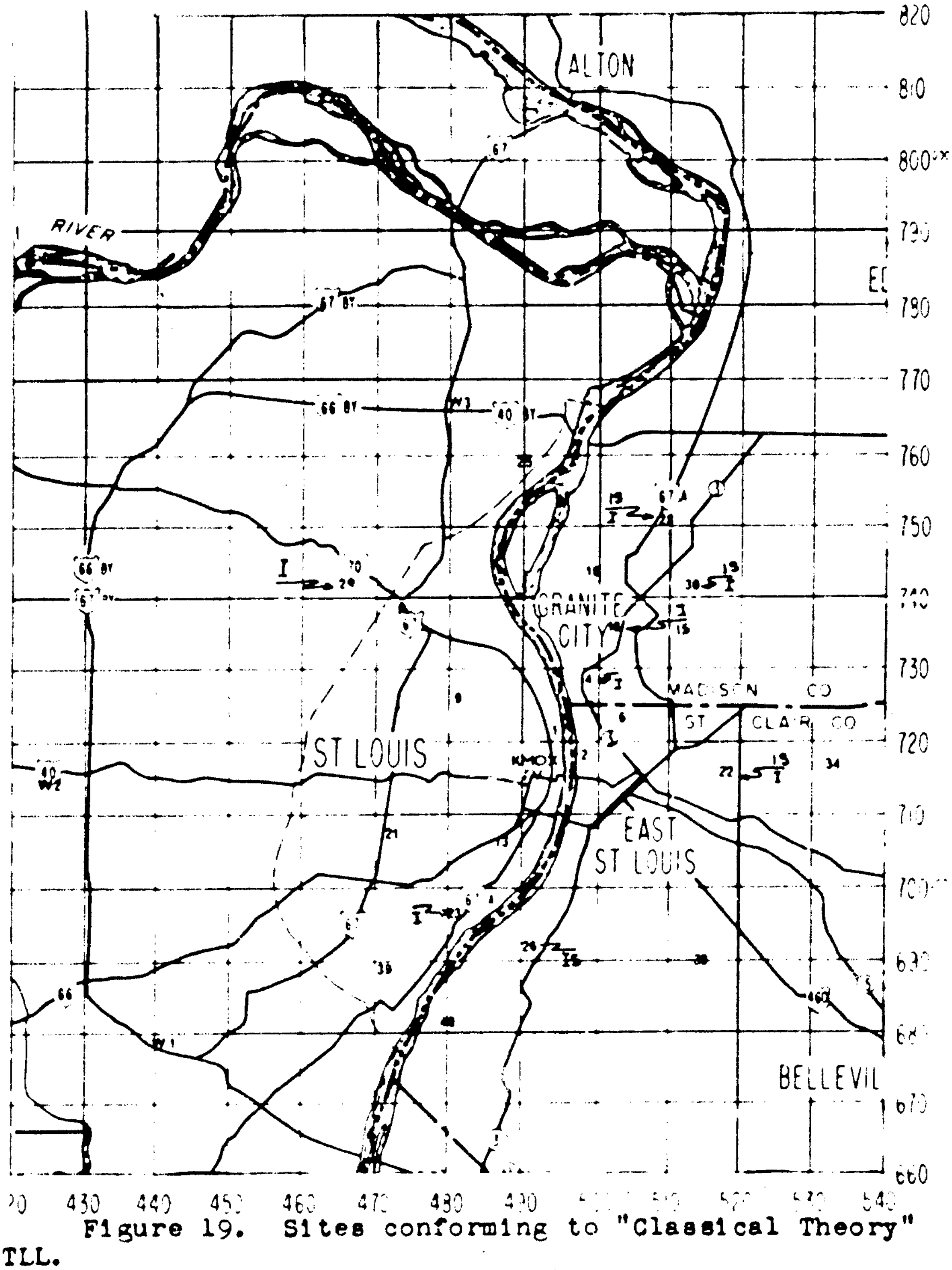


Figure 19. Sites conforming to "Classical Theory"

TLL.

Concentration-Lapse Rate (Maximum)

Concentration-Lapse Rate (Secondary Maximum)

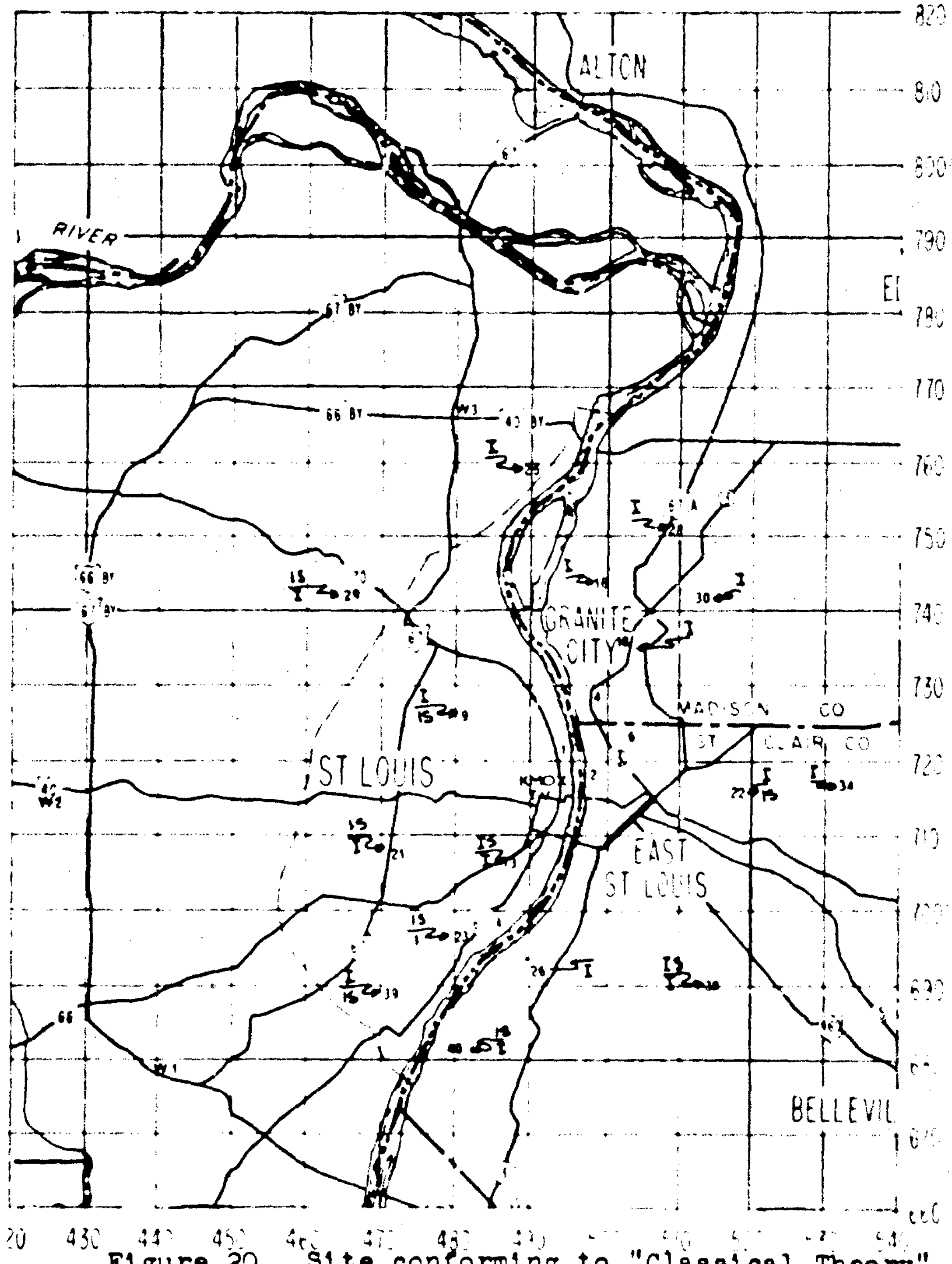


Figure 20. Site conforming to "Classical Theory"
THL.
Concentration-Lapse Rate (Maximum)
Concentration-Lapse Rate (Secondary Maximum)

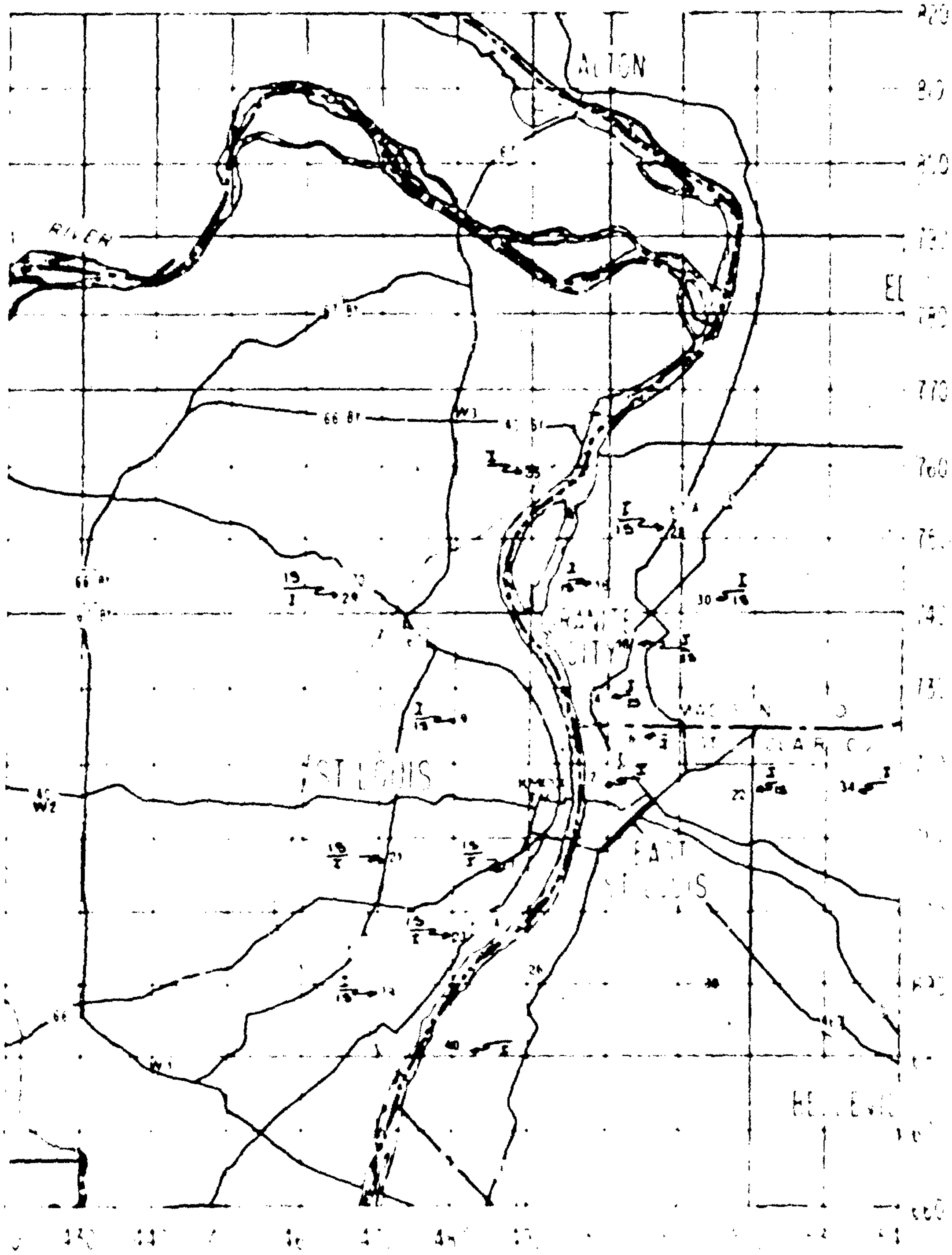


Figure 21. Sites conforming to "Classical Theory" TAL.

<u>Concentration- Lapse Rate (Maximum)</u>
Concentration- Lapse Rate (Secondary Maximum)

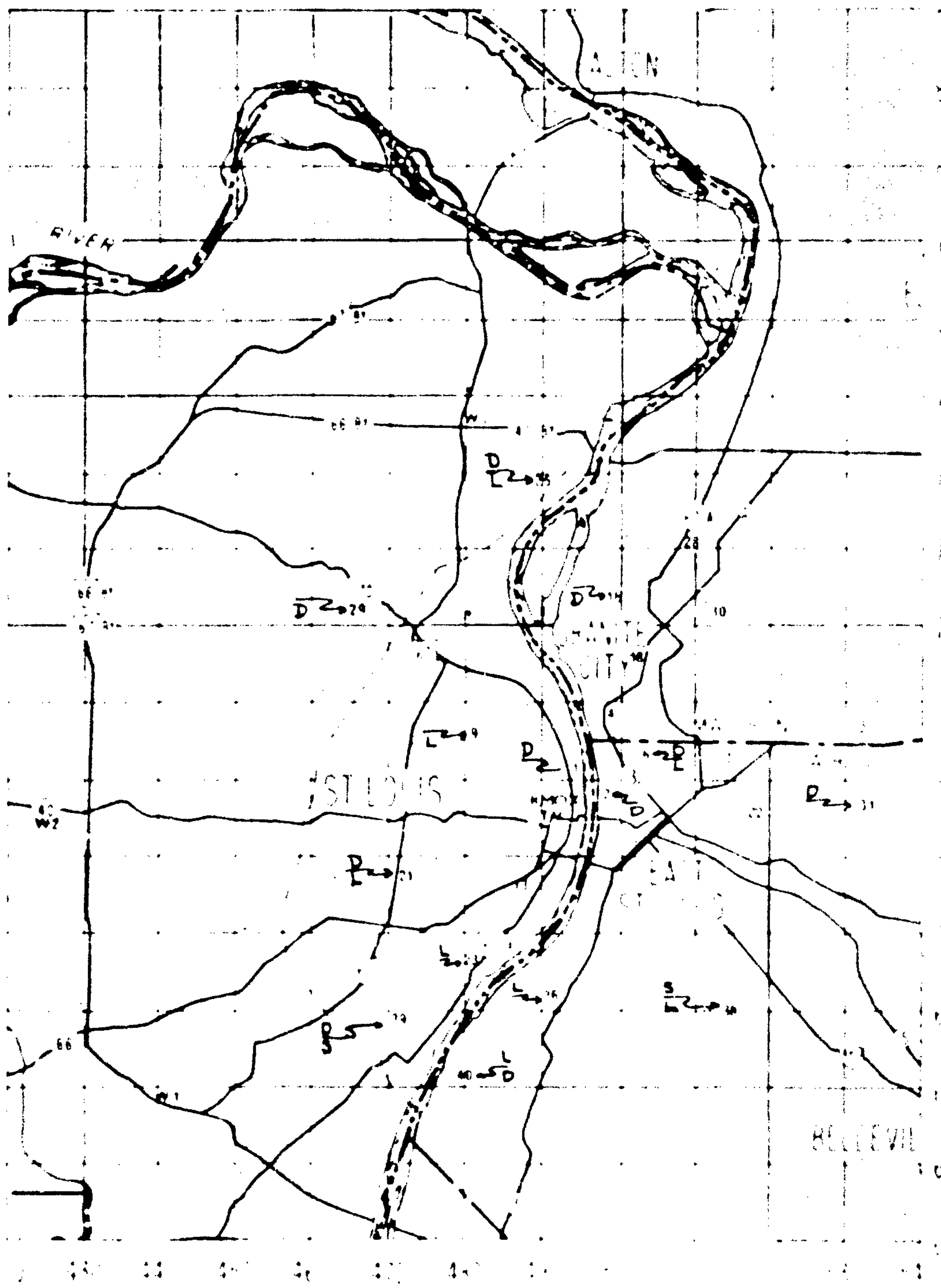


Figure 22. Sites not conforming to "Classical Theory" TLL.

Concentration-Lapse Rate (Maximum)

Concentration-Lapse Rate (Secondary Maximum)

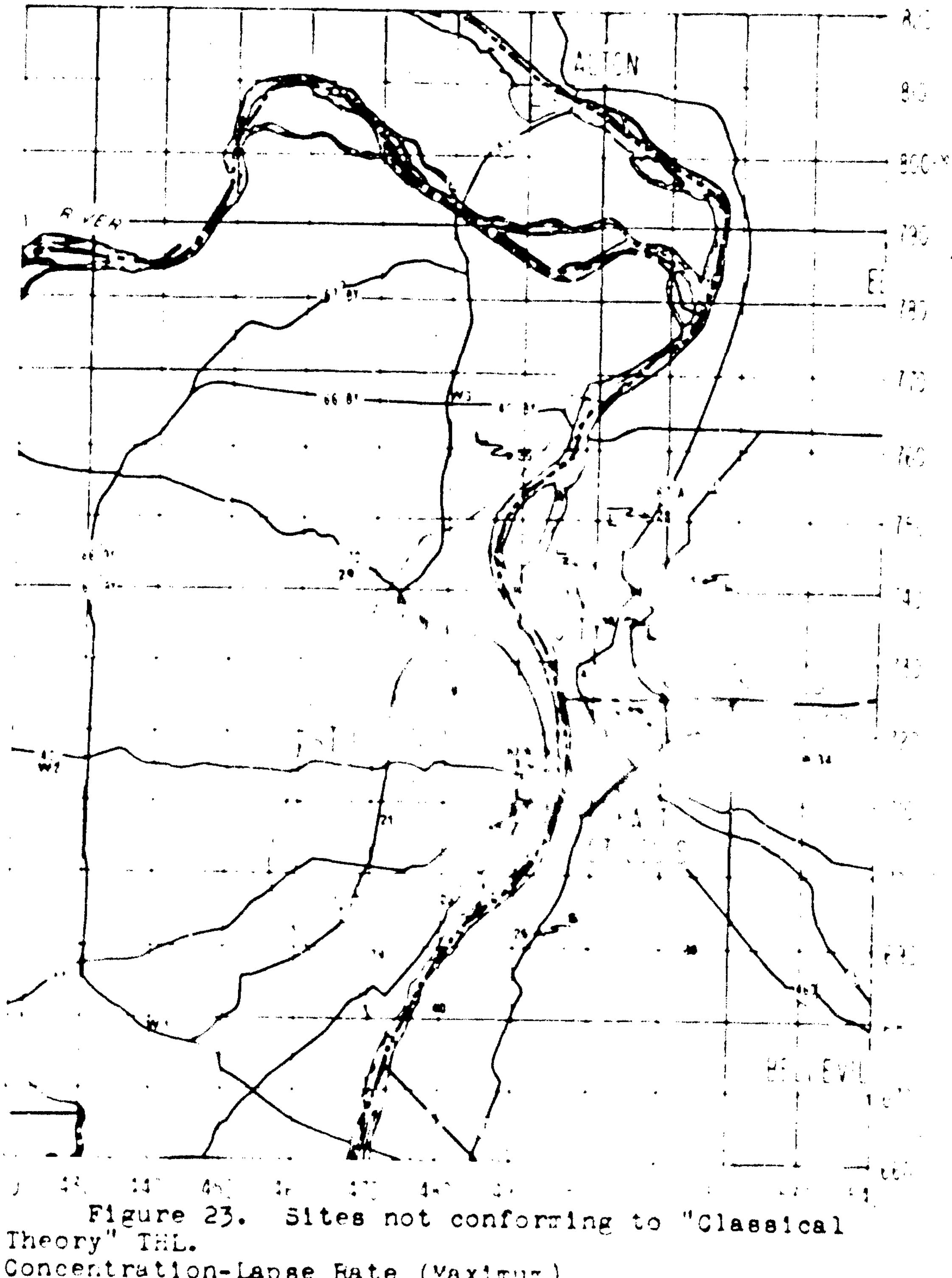


Figure 23. Sites not conforming to "Classical Theory" THL.
<u>Concentration-Lapse Rate (Maximum)</u>
Concentration-lapse Rate (Secondary Maximum)

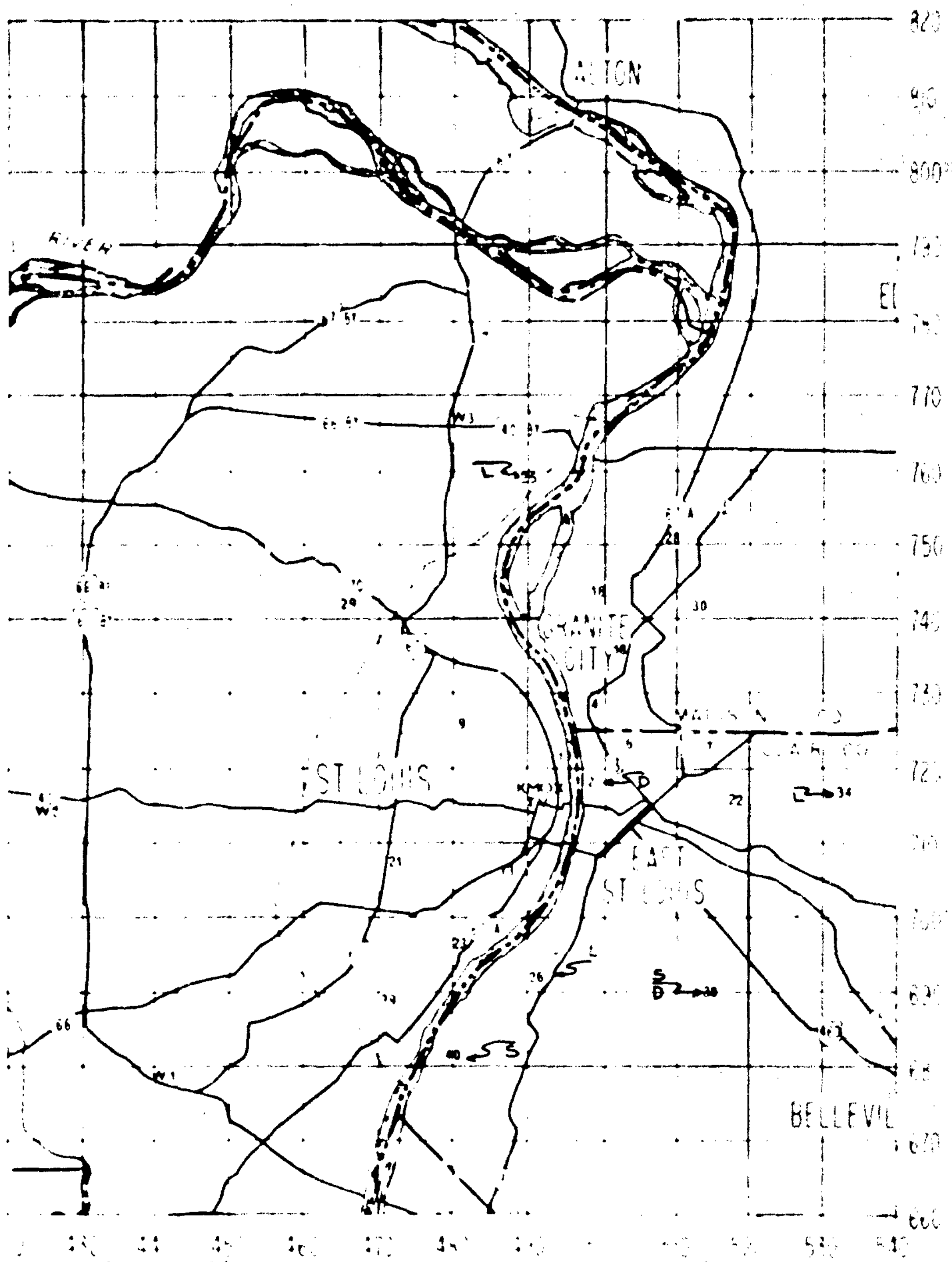


Figure 24. Sites not conforming to "Classical Theory" TAL.

Concentration-Lapse Rate (Maximum)
Concentration--Lapse Rate (Secondary Maximum)

TOWER LAPSE RATE-CONCENTRATIONS

The sulfur dioxide concentrations at various sites were examined to determine their relationship to the tower temperature-difference according to the five lapse rate categories described above in the vertical temperature differences section. The percentage frequencies were determined for concentrations categories equal to or greater than .00 less than .01 PPM, equal to or greater than .01 less than .03 PPM, equal to or greater than .03 and less than .05 PPM, and greater than .05 PPM and the average concentration (microgram per cubic meter) for the duration of each lapse rate condition.

As a first approach, one would expect maximum concentrations to occur with a stable lapse rate; primarily with an inversion, secondarily with an isothermal condition. The lapse rate condition versus sulfur dioxide concentrations were computed for each site using the three temperature-differences measured on the tower.

The average site concentrations for each layer lapse rate were then examined for conformity to the "Classical Theory". The deviating and conforming sites were plotted on charts to see if there was an areal distribution of the abnormalities (figures 19, 20, 21, 22, 23, 24). Only sites 13 and 22 conformed in all cases. Site 22 is located in the flood plain and site 13 is located on high ground.

On examining the anomaly charts, we find the TLL Chart (figure 22) shows the greatest number of deviations. The deviations are dispersed throughout the sampling area. Thus, there is not an apparent topographical reason for the deviations from the "Classical Theory".

The THL and TAL anomaly charts (22) (23) show a relationship with the topography. None of the high ground stations are displayed on these charts. The chart shows the THL anomalies occurring mostly in the northern flood plain sites and TAL anomalies at the southern flood plain sites.

The maximum concentrations occurring during other than stable atmospheric conditions would indicate that the "fumigation" process is of considerable importance at these sites. This is further supported by the greater number of deviations with TLL. Thus, we would conclude at selected sites, more sulfur dioxide is collected during unstable conditions. The THL and TAL are equally representative of "Classical Theory".

Examining extended lapse rate conditions, Table 3 shows superadiabatic and inversion conditions lasting ten hours or more.

TEMPERATURE DIFFERENCES KMOX TV TOWER VS. MISSISSIPPI RIVER BOTTOMS

Arnold (1) mentions the difference between temperature soundings, made with a Wiresonde Set AN/UMQ-4, at the WEW Tower in the Mississippi River bottoms and at the KMOX TV Tower. The WEW Tower is six and one-half miles slightly south of due east from the KMOX TV Tower. It is located at the intersection of Bunkum Road and the Harding ditch. The ground elevation at WEW is 415 feet MSL. An analysis of Arnold's data covering the period September 6 to November 30 is shown on Table 4.

Table 4. Comparison: KMOX TV Tower exceeds WEW wiresonde Temperature

September 6, 1963 to November 30, 1963

Level Feet	Sunrise	Sunset
455	48%	56%
125	35%	68%
GND	43%	44%
	October, 1963	
455	75%	54%
125	92%	67%
GND	62%	71%
	November, 1963	
455	79%	66%
125	87%	66%
GND	32%	38%
	Total Observation Period	
455	65%	58%
125	96%	66%
GND	46%	50%

Arnold determined the height of the kytoon by sighting it through a clinometer and then reading the height from a table supplied with the wiresonde and adjusted for five percent altitude loss due to mooring cable sag. His lowest ascent was 800 feet. This experience of the author of this thesis indicates a one degree error with a clinometer sighting is quite feasible. Therefore, at 800 feet and with a 2,200 feet mooring cable, the sighting error would result in approximately 38 feet altitude error or a $\pm$0.14 F. This is only slightly higher than the KMOX TV Tower temperature error, and well within Arnold's calibration check, a deviation of plus 0.4 F with a thermograph one-half mile away.

This indicates that there is, as one would expect, a different vertical thermal structure between the central city versus the flood plain interurban area. Because of a possible mean error of plus .04 F we can only consider this as an indicator and attempt to draw some inferences from it.

In the winter with the wind blowing heated air from the central city, one would expect stablization of the boundary layer of the atmosphere, resulting in more stable conditions in the suburban areas.

Also analysis reveals on only four occasions did an isothermal or inversion condition not exist at sunrise

and sunset at the KMOX Tower. Two times during the period there was not an inversion in the KMOX Tower, while one existed at WEW, and on one occasion an inversion existed at KMOX and none at WEW. The inversions at WEW were generally stronger than at KMOX.

WIND DIRECTION AND STABILITY

The complexity of the air pollution problem becomes more evident upon examining figure 25. Entered on the chart is the; wind direction, lapse rate conditions for the THL and TLL, and strength of the inversions, site concentrations per concentration-day, mean and median concentration for the sampling period, and directions from which maximum concentrations occur. The day of the week is entered since a possible decrease in industrial activity over the week end would cause a decrease in concentration. The stability category hour sections were divided into THL on the top half and TLL on the bottom half. The inversion category was further classified according to intensity. A bar covering only the lower one half of the layer's portion signifies a weak inversion, i.e. less than plus 1.0 F. A bar covering the entire layer's hour portion was used to indicate a strong inversion of plus 1.0 F or greater. The concentrations have units of PPHM to the nearest tenth of a PPHM.

An inversion of ten hours or more was the criteria for the listed days with the exception of January 16-17 and February 2-3. Site 25 experienced the maximum concentration collected during the sampling period on January 16-17. February 2-3 was arbitrarily selected as a week end day with a minimum of inversion

occurrences. Note also at the extreme right of the chart, the concentration day, December 31-January 1, is out of calendar sequence.

In the following discussion ideal conditions will mean a stable lapse rate and wind blowing from the directions listed in Table 2, station 4 (the winds recorded at the 127 foot level at the TV Tower). "Proper" will refer to winds blowing from pollution source regions, and "poor" or "wrong" refer to winds not blowing from pollution source regions as analyzed before.

Considering Site 39, we find ideal stability and wind direction during the sampling period on December 25-26, yet we note the concentration is exceptionally low for the site. On January 4-5 with virtually the same conditions as above, we note the maximum concentration of the sampling period occurred. Hence we must know what is occurring at the potential sources. Possibly the prime source, for sulfur dioxide at Site 39, was shut down for the Christmas holiday.

With Site 39 under a strong inversion and proper wind direction, we note the occurrence of the period of maximum concentration on January 7. On January 5 a ILL weak inversion and poor wind direction produced a concentration lower than the mean. January 17 with the wind blowing from the source region and under predominantly lapse conditions, we again realize a

concentration above the mean. On December 5 another variable is injected; stable TLL and unstable THL occurred with a concentration of 0.3 PPHM. A concentration of 0.3 PPHM is measured on January 4 and 16. Here the winds are still from the wrong direction, but more stable conditions prevail. Under these varying conditions, equal concentrations occur. These were not ideal conditions as on January 7, and as a consequence, not as high concentrations.

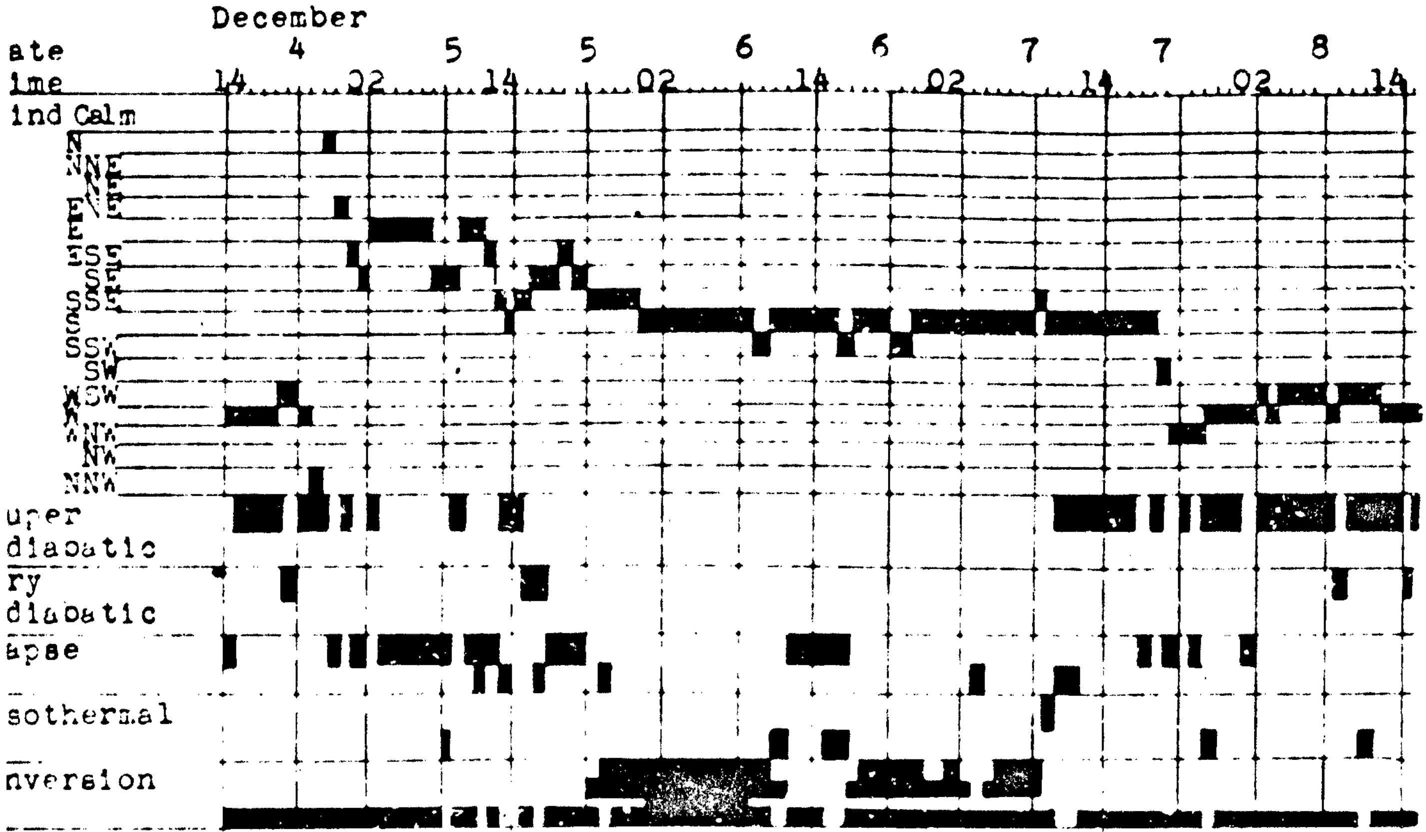
The maximum concentration of 9.2 PPHM at site 40 occurred in a sample collected December 24 and 25, not shown on the chart. The wind direction during the twenty-four hour period was favorable and there was a strong THL and TLL inversion for five hours. It is possible that the bulk of the sample was collected during this short stable period. The second highest concentration occurred December 31-January 1. Here THL indicated a variable weak to a strong inversion. The wind direction was favorable, coming first from the northeast quadrant and later swinging to the southwest quadrant. Both were shown previously to be conducive to high concentrations (figure 16). February 10 the winds held predominantly from the northeast quadrant with a weak inversion noted in TLL and THL which was mostly unstable. The resulting concentration was higher than the mean of 1.7 PPHM. January 4-5

shows a strong inversion lasting for fourteen hours and a TLL inversion for twenty-three hours, of which ten hours were strong inversions. A maximum of plus 5.9 F was recorded for TAL at 0800 on the 5th with THL maximum of plus 4.8 F. The winds were generally proper with a concentration well above the median and mean concentration. It appears that conditions in general were more ideal than on December 24-25.

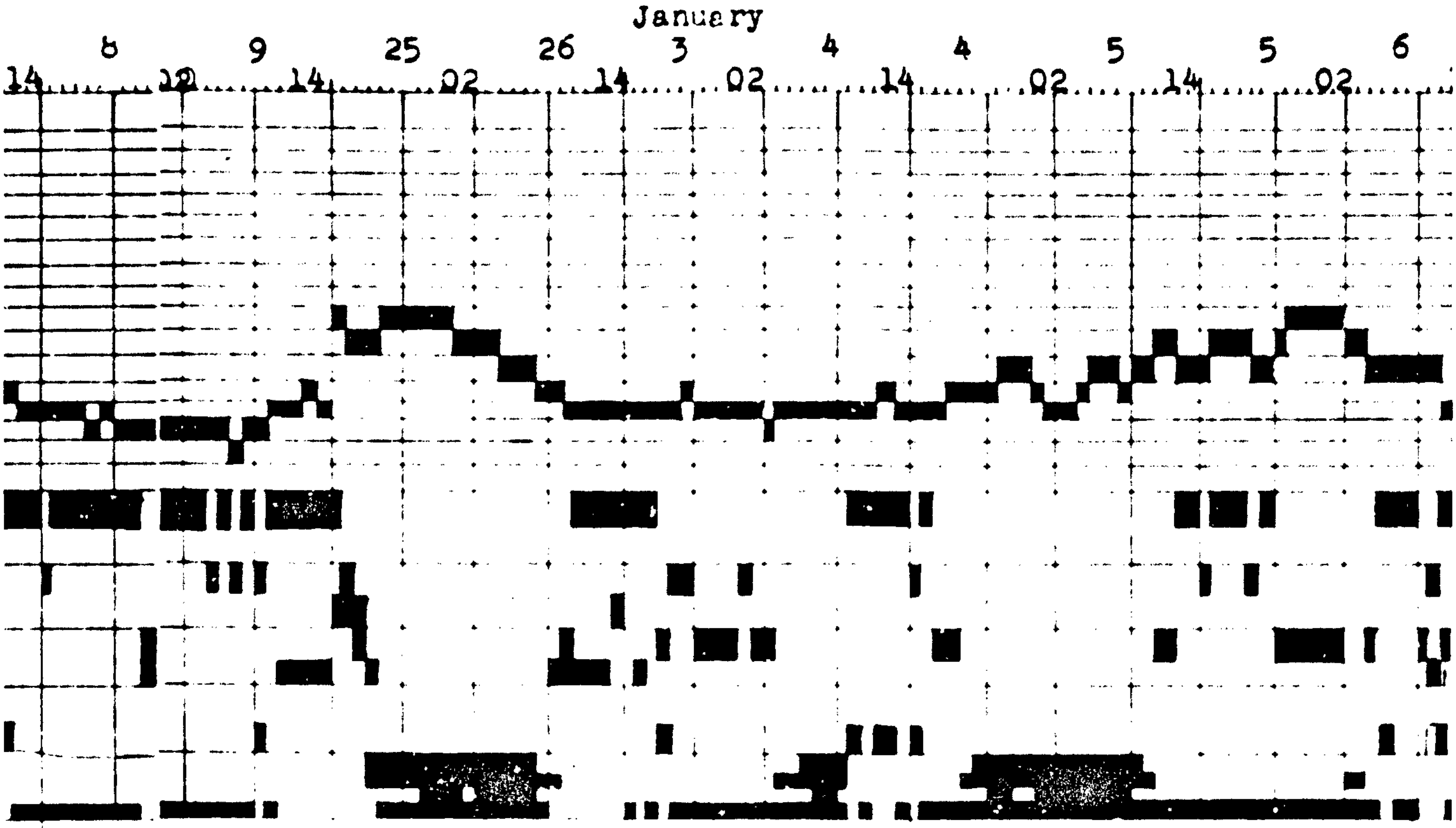
Investigating the twenty-four hour sulfur dioxide concentrations at site 25 we find a paradox. The maximum concentration occurred on January 17 under predominantly lapse conditions, with the wind direction coming from the area of maximum pollution as determined by the pollution rose. Concentrations collected on January 13 under ideal conditions for site 25 yielded twenty-four hour concentration of 7.6 PPHM; this was less than the maximum concentration for the sampling period under less than ideal conditions. January 19 and January 20, site 25 concentrations were 5.3 and 1.1 PPHM respectively, not shown on the chart. For the January 19 sample THL recorded seventeen hours of lapse, one hour superadiabatic and six hours of weak inversion. THL at the same time reported four hours dry-adiabatic, three hours superadiabatic, seven hours lapse, and seven hours of continous inversion in which three hours were strong inversion. Winds were generally proper holding from the south.

The January 20 concentration day shows ILL conditions to be; one hour weak inversion, one hour isothermal, sixteen hours lapse and six hours superadiabatic. THL conditions were; ten hours lapse and fourteen hours superadiabatic. Wind conditions were proper for only twelve hours.

December 5-6 shows ideal conditions and we find a negligible concentration. Thus, there is again another factor--most likely the pollutant source. This dramatically points out the necessity of carefully examining all factors involved: the amount of emission, transport of pollutant, atmospheric stability, and the chance of possible error in sample analysis.

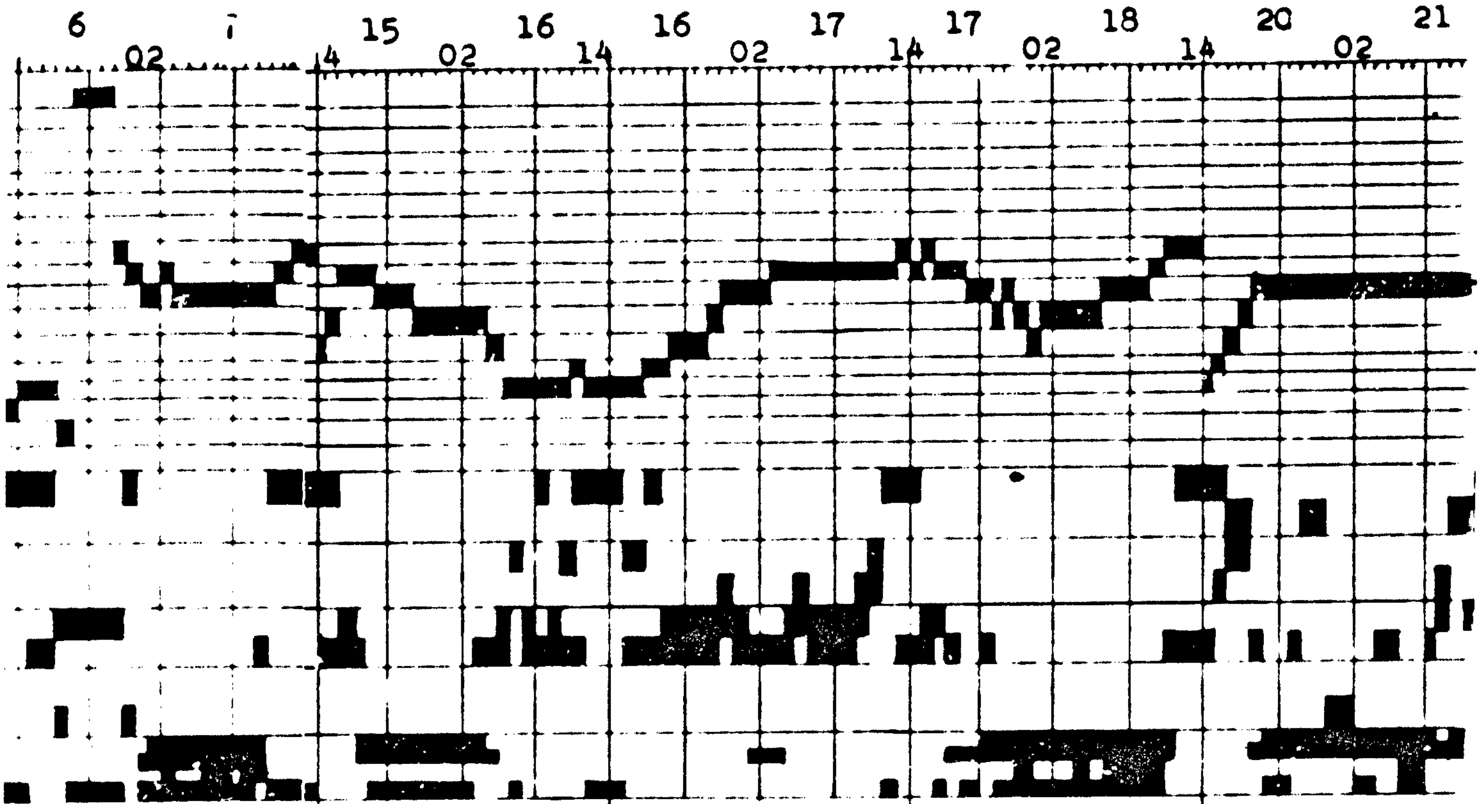


ite--Conc. -Mean Conc. -Median Conc. aximum Conc. rections	Days of Week pphm Wednesday Thursday	Thursday Friday	Friday Saturday	Saturday Sunday
25 4-1.9 2- .9 S SSE SSW SW	0.1	0.0	0.3	0.0
29 -2.6 -1.4 SSE SE SSE Calm	0.3	4.2	Msg	Msg
39 -2.7 -1.8 S SSW ENE SSW	0.4	2.4	3.2	0.3
40 -1.7 -1.5 ENE SSW SW NE	0.1	0.6	1.1	1.8



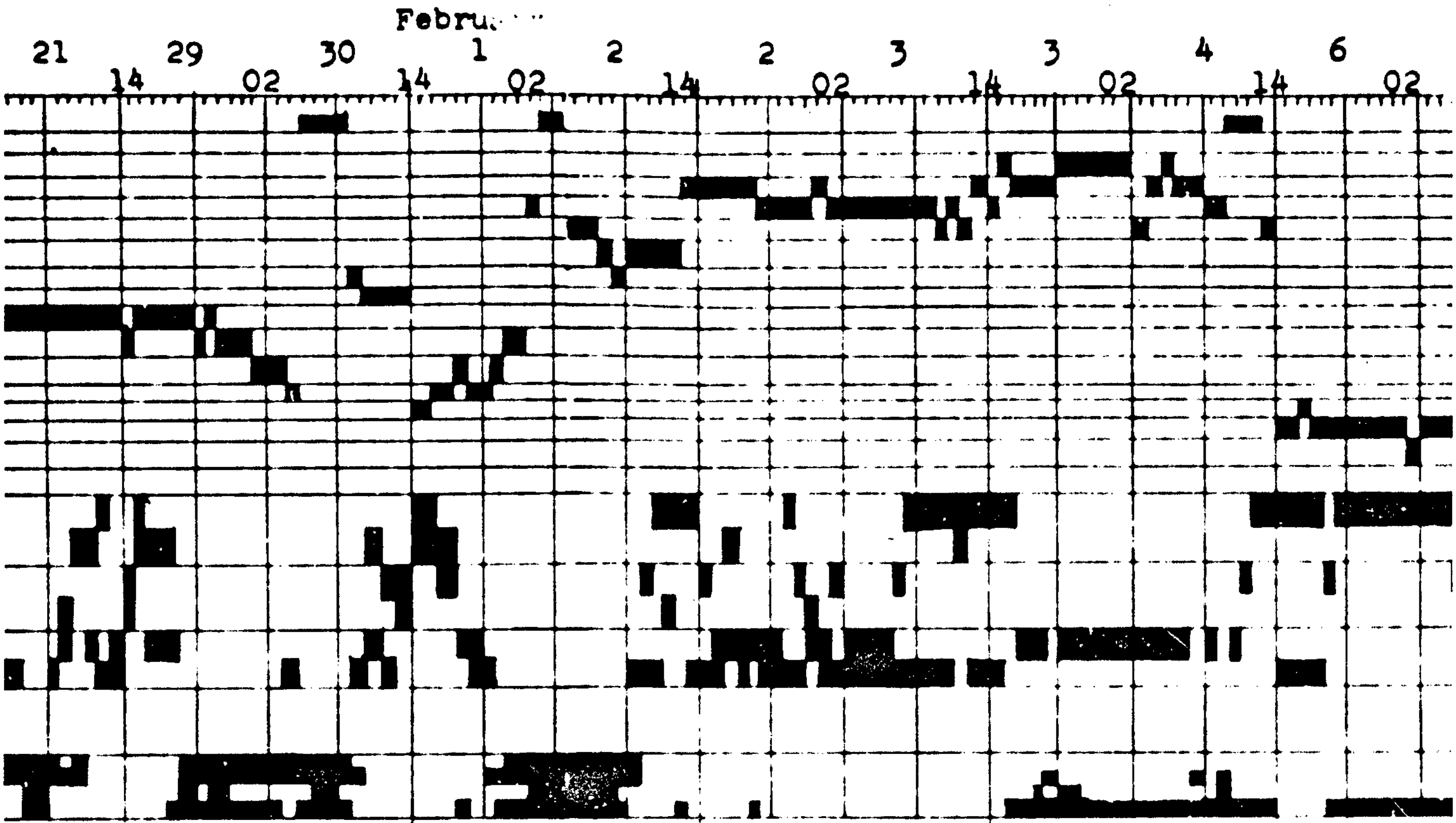
Sun day Mon day	Wednesday Thursday	Friday Saturday	Saturday Sunday	Sunday Monday
0.1	Msg	0.7	5.4	3.2
Msg	Msg	0.3	2.2	2.1
0.8	0.6	3.5	13.6	3.2
1.4	Msg	Msg	4.1	1.7

B



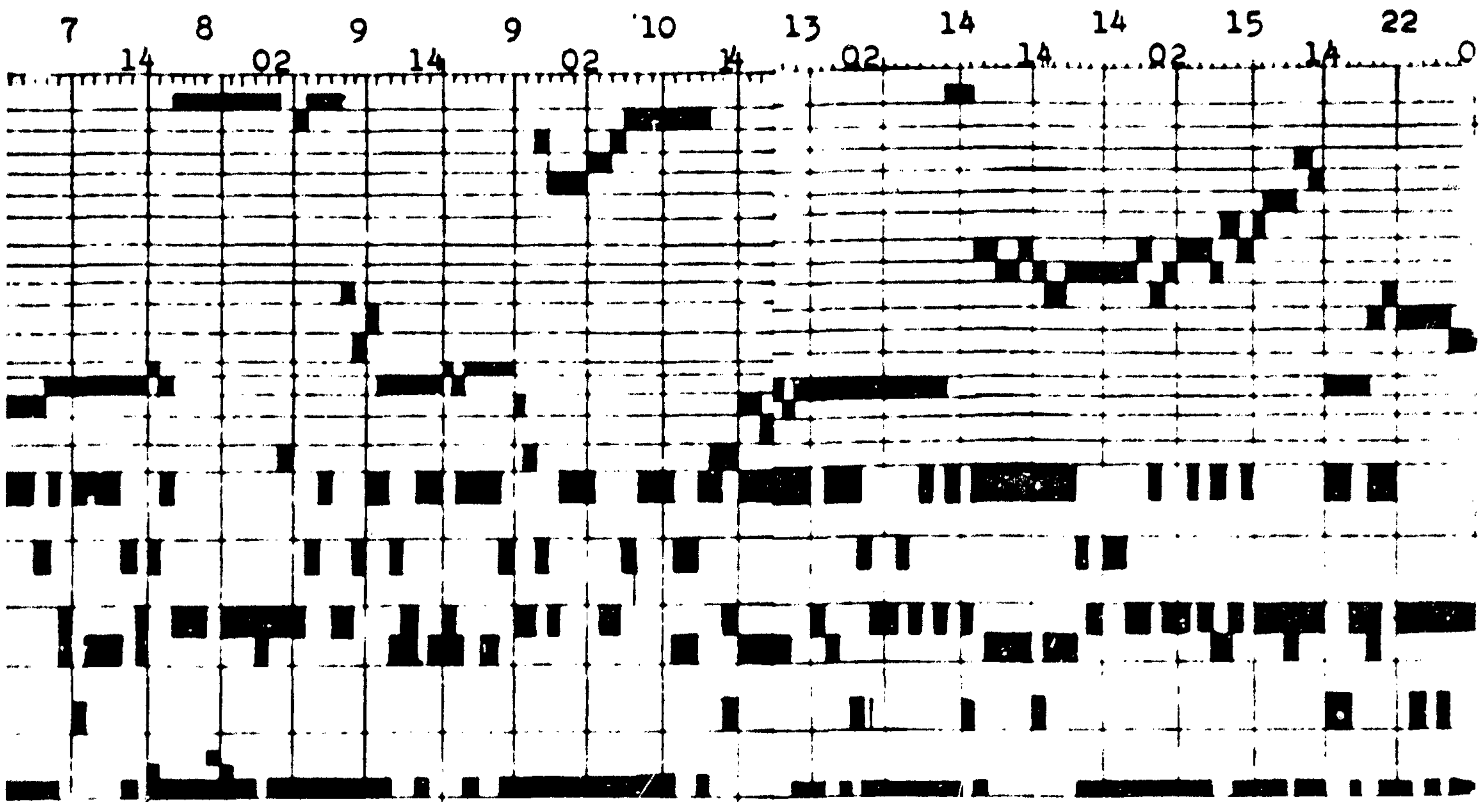
Monday Tuesday	Wednesday Thursday	Thursday Friday	Friday Saturday	Monday Tuesday
6.2	0.5	8.7	7.6	6.6
20.6	0.3	3.4	5.8	4.4
6.6	2.0	1.3	3.4	12.6
1.2	0.3	1.7	1.6	1.5

C



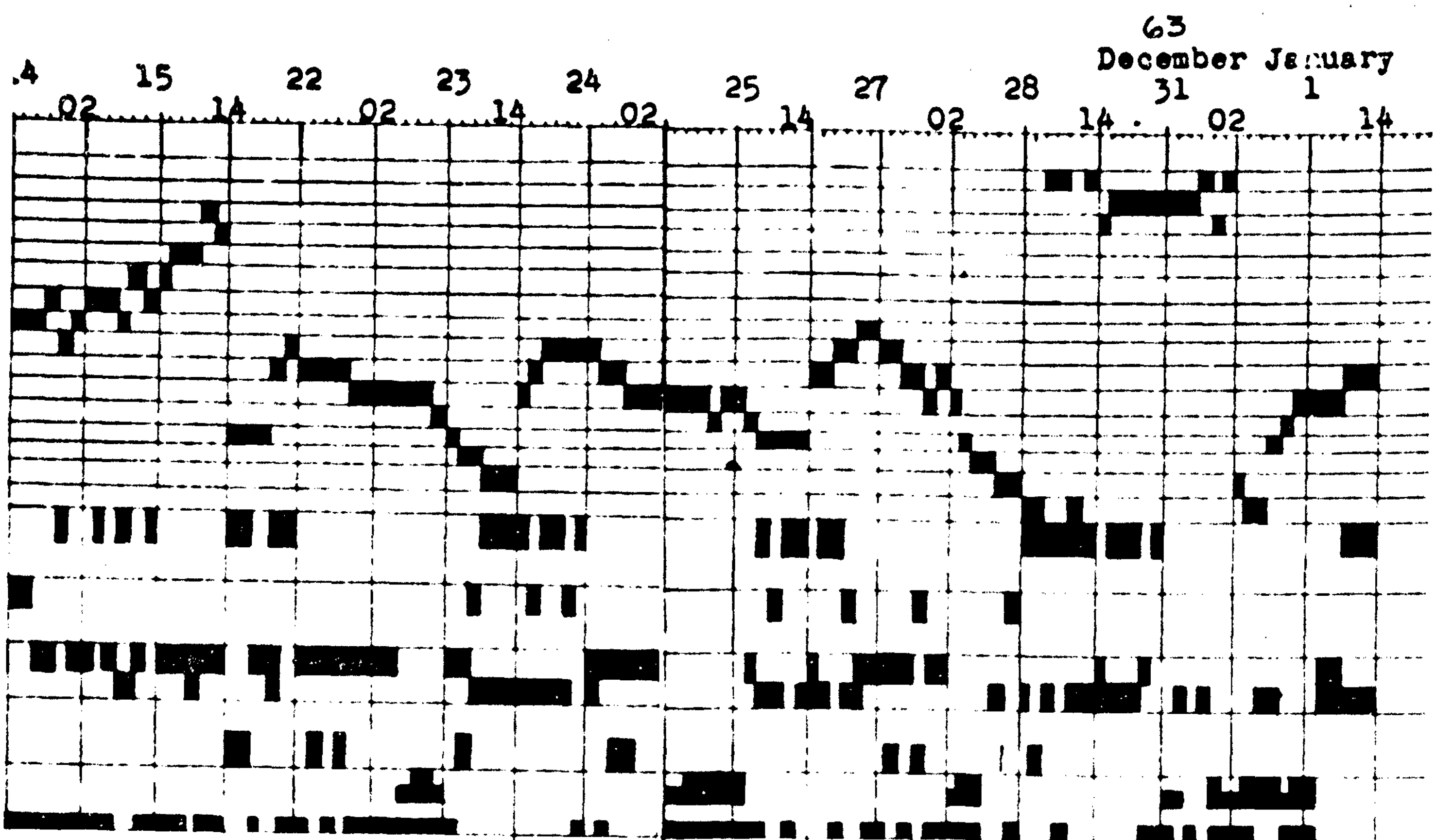
y ay	Wednesday Thursday	Saturday Sunday	Sunday Monday	Monday Tuesday	Thurs Frida
5	6.1	0.3	0.2	0.7	0.1
4	1.7	4.1	2.6	5.5	0.
5	5.7	1.9	2.2	5.6	0.
5	2.0	2.3	0.9	1.6	0.

D



sday ay	Saturday Sunday	Sunday Monday	Thursday Friday	Friday Saturday	Sat Sun
.1	0.3	0.3	0.6	1.0	[illegible]
.1	0.2	0.4	1.1	4.9	[illegible]
.2	0.3	0.7	0.8	0.9	[illegible]
.3	1.4	2.7	0.3	0.8	

E



Friday Saturday	Saturday Sunday	Monday Tuesday	Thursday Friday	Tuesday Wednesday
1.0	2.2	2.7	2.1	3.2
4.9	1.9	2.8	2.6	4.5
0.9	4.7	3.3	1.6	Mag
0.8	1.8	1.1	1.3	6.3

F

CONCLUSIONS

1. A comprehensive investigation of air pollution problem requires; an intimate knowledge of the emission sources, the pollutant samples of a shorter time duration than the twenty-four hour sulfur dioxide sample used in this thesis, and knowledge of what is occurring in and above the first five hundred feet above the surface.

2. The data on lapse rates and concentrations indicate stronger average concentrations occurring, in many cases in other than stable conditions. These results are certainly subject to question. The assumption that the pollution was uniform throughout the twenty-four hours is questionable since a diurnal variation in the sulfur dioxide concentration has been shown in the studies by Schuememan (27), Murino (24) in the St. Louis area, also at Nashville (37) and Birmingham (18). In the St. Louis area the samples used by Murino and Schuememan were taken in the source regions, thus some other diurnal variation may occur in remote sites. Regardless of the errors that may be introduced by the assumption, it would seem that the large number of cases showing maximum concentrations occurring during unstable conditions show that "fumigation" is an important process in the St. Louis metropolitan area. The maximum average concentrations were indicated for all sulfur

dioxide sites, above 500 feet MSL, during stable conditions at the THL (figure 20). The THL appears to fulfill the "Classical Theory" for sites above 500 feet MSL.

3. The pollution roses based on wind data at station 4 (Table 2) indicate directions from which maximum concentrations originate. The directions indicated for the twenty sites in this study (figure 16) appear to be realistic. With samples of shorter duration, these will be further refined. Station 4, the tower's lower anemometer, seemed to be most representative when compared with the other four wind stations.

4. KMOX TV Tower temperature differences show possible man-made six hour periodic influences on the TLL. The THL was shown to be more unstable than TLL.

5. Analysis of Arnold's (1) data shows a difference in the vertical thermal structure between the KMOX TV Tower and the Mississippi River flood plain during the fall season, and this author feels this would be accentuated in winter time.

6. There was no build-up in the pollution level indicated during the longer stable periods. Such build ups would be more typical of fall when there are stagnation periods lasting for as long as five days.

7. The single twenty-four hour sample of the sulfur dioxide concentrations is more appropriate for an air quality study than for a meteorological investigation.

SUGGESTED FURTHER RESEARCH

1. Very little data have been published regarding the vertical thermal structure over urban areas. The short three-month period suggested a periodic character in the TLL. Since it was held to 0600, 1200, 1800, and 2400, this may be a man-made influence. The reason for this phenomenon should be determined.

2. Kytoon or similar temperature measuring techniques should be used in different locations in the urban area. This would allow determination of the atmospheric stability above the tower and help to interpret fumigation situations.

3. Thermal mapping of the atmosphere and ground surface in metropolitan St. Louis would determine the center of the heat island and thermal variations across the metropolitan area. These variations may be related to pollutant concentrations.

4. Sulfur dioxide should be sampled in the fall so as to include a prolonged period of stagnation. Particular attention should be given to examining pollutant build up over the stagnation period.

5. The inter-relationships between broad scale synoptic patterns and metropolitan vertical temperature structure should be investigated.

6. Tower wind gustiness and pollutant concentrations, wind direction flucuations and their effect on sulfur dioxide concentrations should be examined.

7. In the St. Louis-East St. Louis area wind observations in the Mississippi River flood plain should be made. Under stable conditions, there could be significant differences.

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VITA AUCTORIS

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1931	Born August 20, 1931, Kansas City, Missouri.
1948	In May, graduated from North Kansas City High School, North Kansas City, Missouri.
1953	In May, received a Bachelor of Science degree in Education from Central Missouri State College, Warrensburg, Missouri.
1954	Completed Basic Meteorology training at Saint Louis University under the auspices of the United States Air Force Institute of Technology.
1954	From 1954 until 1963, served as an Air Force Weather Officer at Kunsan, Korea; Oxnard Air Force Base, California; Pease Air Force Base, New Hampshire; and as a Weather Reconnaissance pilot at Guam, Marianas Islands.
1963	Assigned to United States Air Force Institute of Technology for Graduate study in Meteorology at Saint Louis University.

PENDIX A. SULFUR DIOXIDE NETWORK

APCA RECOMMENDED STANDARD METHODS OF CLASSIFICATION

NA

te	Zone	Sources	Direction	A
1	FF	2 steam generating power plants	N	Ir
		1 chemical plant	E	Ir
		Several industrial and commercial power plants	S	S
			W	C
9	BD	Low income residential area	N	Re
		Considerable space heating accomplished with hand fired units	E	Re
		Small heavy industrial area approximately 1/2 mile away	S	Re
			W	Re
3	BF	Industrial power plants approximately 1/3 mile away in east to south quadrant	N	S
			E	R
			S	R
			W	R
1	AE	Commercial and industrial activity 1/3 mile in	N	R
			E	R
			S	Re
			W	Re
3	CB	Commercial activity to north and east	N	C
		Residential to south and west	E	C
			S	R
			W	R
5	AA		N	R
			E	R
			S	R
			W	R
9	AA	Shopping center 1/2 mile south	N	R
			E	R
			S	R
			W	R
9	AA	Chemical plant 1/2 mile west	N	R
		Cement plant 1/2 mile south	E	R
			S	R
			W	R
2	FF		N	I
			E	I
			S	I
			W	I
4	AB	Power plant 1/3 mile southwest	N	R
		Mixed industrial 1/3 mile east	E	R
			S	R
			W	R

NARRATIVE CLASSIFICATION BY DIRECTION FROM SAMPLING STATION

ion	Activity
	Industrial
	Industrial, commercial and storehouses, Mississippi River 1/3 mile
	Storehouses and industrial
	Commercial and industrial
	Residential
	Residential and commercial, with industrial area approximately 1/2 mile
	Residential and commercial
	Residential
	School and residential
	Residential, with industrial 1/3 mile away
	Residential, with industrial 1/3 mile away
	Residential and commercial
	Residential with commercial and industrial activity 1/3 mile away
	Residential
	Residential
	Residential with commercial and industrial activity 1/4 mile away
	Commercial
	Commercial
	Residential
	Residential
	Residential
	Residential
	Residential
	Residential
	Residential
	Residential
	Residential with commercial 1/2 mile
	Residential
	Residential
	Residential
	Residential with cement plant 1/2 mile south
	Residential with chemical plant 1/2 mile west
	Industrial
	Industrial
	Industrial
	Industrial
	Residential with commercial 1/3 mile
	Residential with industry 1/3 mile
	Residential with power plant 1/3 mile
	Residential

ɔpendix A continued

APCA RECOMMENDED STANDARD METHODS OF CLASSIFICATION

.te	Zone	Sources	Direction
6	FF	Large industry but not heavily developed	N E S W
.6	AA	Heavy industrial 1/3 mile southeast	N E S W
.8	FB	Industrial west, residential and commercial east	N E S W
!2	AA	Chemical plant 1 mile north	N E S W
!6	AA		N E S W
!8	GG		N E S W
;0	AB	Heavy industrial 1 mile south	N E S W
;4	AG		N E S W
;8	AA		N E S W
·0	AA		N E S W

NARRATIVE CLASSIFICATION BY DIRECTION FROM SAMPLING STATION

Direction	Activity
N	Industrial } large industry, not heavily developed
E	Industrial
S	Industrial
W	Industrial
N	Residential
E	Residential
S	Residential with some heavy industry 1/3 mile
W	Vacant land
N	Industrial-residential
E	Residential-commercial
S	Industrial-residential
W	Residential-commercial
N	Residential with commercial activity 1/4 mile - chemical plant 1 mile
E	Residential
S	Residential
W	Residential
N	Residential
E	Residential
S	Residential
W	Residential
N	Rural
E	Rural-residential 1/2 mile
S	Semi-rural
W	Rural
N	Residential
E	Residential
S	Residential-heavy industrial 1 mile
W	Residential - apartments
N	Rural
E	Rural
S	Residential-rural
W	Rural
N	Residential
E	Residential
S	Residential
W	Residential
N	Residential
E	Residential
S	Residential
W	Residential

Appendix A (continued)

Sulfur Dioxide Network

Classification of the Area

The area served by each jar will be classified according to the character of 'urban activity in the vicinity of the station. The type of activity within one quarter mile of the station will determine the primary classification. A secondary classification will be determined by the type of activity withing one-half mile from secondary classification, such as Zone AA or AF etc.

Note should be made of amy major source or sources of sulfur dioxide discharged within one mile of the station.

The areas will be classified as follows:

Zone A	Residential, low density (less than ten units/acre and non rural). A dwellin unit= one family occupancy
Zone B	Residential high density seven to ten units/acre
Zone C	Commercial neighborhood Shopping district
Zone D	Commercial central district
Zone E	Industrial low air pollution potential
Zone F	Industrial with air pollution potential
Zone G	Rural one dwelling/five acres or larger area

APPENDIX B

SO2 POLLUTION ROSES 4 1

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

WND DIR	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
N	.305	1.711	2.689	1.466	6.173	4.687
NNE	.244	.366	.733	.489	1.833	5.097
NE	.244	.427	.122	.183	.977	3.403
ENE	.488	.244	0.000	.183	.916	2.799
E	1.344	1.405	.305	1.161	4.217	3.465
ESE	.183	.488	.061	.977	1.711	5.113
SE	0.000	2.750	.122	1.161	4.034	4.491
SSE	.305	1.589	.366	1.222	3.484	5.521
S	.672	3.056	2.567	4.523	10.819	6.048
SSW	.427	.916	.244	5.012	6.601	8.533
SW	.122	.733	.122	2.261	3.239	9.360
WSW	.427	.855	.122	1.955	3.361	7.815
W	3.300	4.951	.427	4.584	13.264	4.946
WNW	3.056	3.422	.366	2.261	9.107	3.758
NW	1.650	4.645	.550	.977	7.823	2.845
NNW	.427	2.995	1.283	.611	5.317	3.760
CALM	0.000	.244	.183	.061	.488	6.130

TOTAL NO. VALID HOURS IN TIME PERIOD 1636

SO2 POLLUTION ROSES 4 2

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

WND DIR	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
N	.611	2.506	1.711	1.955	6.784	4.457
NNE	.427	1.100	1.589	.672	3.789	4.294
NE	.183	.488	.183	.611	1.466	5.374
ENE	.550	.305	.122	.550	1.528	4.133
E	1.344	1.161	.122	.916	3.545	3.057
ESE	1.283	.916	.061	.427	2.687	2.469
SE	.794	3.300	.122	1.405	5.623	3.567
SSE	.672	2.139	1.039	2.261	6.112	5.206
S	.488	2.444	1.894	5.745	10.574	6.581
SSW	.183	1.405	.427	5.134	7.151	8.058
SW	.305	.794	.305	4.462	5.867	8.766
WSW	.427	1.283	.427	2.506	4.645	7.054
W	1.833	3.973	.672	4.400	10.880	5.388
WNW	3.300	2.628	.244	1.772	7.946	3.046
NW	2.261	4.217	.672	2.444	9.596	3.769
NNW	2.872	4.645	1.772	1.161	10.452	2.866
CALM	0.000	0.000	.122	.366	.488	6.447

TOTAL NO. VALID HOURS IN TIME PERIOD 1636

APPENDIX B CONTINUED

SO2 POLLUTION ROSES 4 3

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

WND DIR	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
N	.211	2.824	3.319	.423	6.779	4.208
NNE	.353	.988	.847	.847	3.036	4.778
NE	.211	.423	.282	.423	1.341	4.923
ENE	1.059	.776	0.000	.776	2.612	3.140
E	1.341	.847	.211	1.412	3.813	3.868
ESE	.282	.918	0.000	1.059	2.259	5.088
SE	.494	2.118	.211	1.200	4.025	3.946
SSE	.423	1.906	1.059	2.683	6.073	5.718
S	.847	1.836	2.189	6.638	11.511	6.880
SSW	.353	.918	.070	3.954	5.296	9.142
SW	.282	.918	.353	2.683	4.237	8.688
WSW	.070	.353	.282	2.471	3.177	9.089
W	1.977	3.248	.211	3.601	9.039	5.387
WNW	3.107	3.319	.353	2.612	9.392	4.015
NW	3.248	6.497	.211	2.048	12.005	2.942
NNW	.988	2.754	1.906	.847	6.497	3.784
CALM	0.000	1.200	.282	1.977	3.460	6.628

TOTAL NO. VALID HOURS IN TIME PERIOD 1416

SO2 POLLUTION ROSES 4 4

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

WND DIR	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
N	1.032	3.157	2.185	1.639	8.014	3.946
NNE	.728	1.457	.303	.971	3.460	4.070
NE	1.335	1.092	.303	.667	3.400	2.953
ENE	1.214	.728	.182	1.032	3.157	3.796
E	.546	.667	.121	.607	1.942	3.393
ESE	.182	1.639	0.000	.364	2.185	3.042
SE	.425	2.489	.242	.971	4.128	3.985
SSE	.425	2.428	1.457	1.700	6.010	4.531
S	.850	2.367	1.275	9.775	14.268	8.024
SSW	.060	.971	.182	4.614	5.828	8.559
SW	.121	1.032	.242	4.614	6.010	8.588
WSW	1.821	2.367	.242	2.732	7.164	5.016
W	2.185	4.735	.728	3.217	10.868	4.064
WNW	1.092	3.035	.242	.971	5.343	3.205
NW	1.214	1.214	.425	.789	3.642	3.318
NNW	1.396	1.942	2.489	1.335	7.164	3.865
CALM	0.000	1.457	1.032	1.153	3.642	5.242

TOTAL NO. VALID HOURS IN TIME PERIOD 1647

APPENDIX B CONTINUED
SO2 POLLUTION ROSES 4 5
CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

WND DIR	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL. PERCENT	AVG. UG/CU.M
N	.307	2.338	2.030	1.784	6.461	4.395
NNE	.246	.861	1.169	.738	3.015	4.361
NE	.246	.123	.246	.738	1.353	6.115
ENE	.615	0.000	0.000	1.230	1.846	5.993
E	.553	0.000	.123	.800	1.476	4.395
ESE	.184	.123	0.000	.492	.799	4.923
SE	.246	1.046	.061	.861	2.215	4.733
SSE	.246	2.461	1.353	2.400	6.461	5.220
S	1.169	2.215	1.538	8.123	13.046	6.617
SSW	.307	.615	.307	3.753	4.984	8.815
SW	.430	.430	.184	3.753	4.799	9.912
WSW	1.292	2.030	.123	2.646	6.092	6.215
W	2.461	4.061	.923	4.246	11.692	4.805
WNW	1.107	2.030	.184	1.415	4.738	4.013
NW	1.476	1.415	.246	1.169	4.307	3.887
NNW	1.723	2.030	1.292	.923	5.969	3.439
CALM	0.000	.061	0.000	.184	.246	7.166

TOTAL NO. VALID HOURS IN TIME PERIOD 1625

APPENDIX C

TOWER LAPSE RATES 4 DT 1

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

127-242 FOOT LAYER

LAPSE RATE CONDITION	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
SUPER ADIAB	1.608	5.181	.774	2.501	10.065	4.265
DRY ADIAB.	.476	.893	.119	1.250	2.739	5.672
LAPSE	6.611	14.234	5.955	14.532	41.334	4.504
ISOTHERMAL	1.369	1.905	.952	2.918	7.147	5.237
INVERSION	7.087	12.030	3.633	15.961	38.713	5.298

TOTAL NO. VALID HOURS IN TIME PERIOD 1679. 1673. 1679.

TOWER LAPSE RATES 4 DT 2

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

127-452 FOOT LAYER

LAPSE RATE CONDITION	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M.
SUPER ADIAB	2.211	4.722	.657	2.749	10.340	4.563
DRY ADIAB.	.358	1.494	.418	1.016	3.287	4.597
LAPSE	13.329	24.985	9.025	23.610	70.950	4.447
ISOTHERMAL	.059	.239	0.000	.239	.537	6.203
INVERSION	1.255	2.928	1.374	9.683	15.242	7.599

TOTAL NO. VALID HOURS IN TIME PERIOD 1679. 1673. 1679.

TOWER LAPSE RATES 4 DT 3

CONCENTRATION FREQUENCY-PERCENT TOTAL HRS

242-452 FOOT LAYER

LAPSE RATE CONDITION	PPM .00-.01	PPM .01-.03	PPM .03-.05	GREATER THAN .05	TOTAL PERCENT	AVG UG/CU.M
SUPER ADIAB	6.397	14.532	[illegible]	11.018	38.991	4.152
DRY ADIAB.	1.365	4.645	[illegible]	3.216	10.661	[illegible]
LAPSE	5.419	12.209	4.169	12.924	34.723	4.486
ISOTHERMAL	.178	.238	.119	.416	.952	4.903
INVERSION	1.191	2.620	1.310	9.589	14.711	8.093

TOTAL NO. VALID HOURS IN TIME PERIOD 1679. 1673. 1679.

APPENDIX D

PERCENT OF LAPSE RATE PER HOUR OF DAY

FREQUENCY OF LAPSE RATE PER HOUR OF DAY

127-249 FOOT LAYER

HOUR	SUPER ADIABATIC	DRY ADIABATIC	LAPSE	ISOTHERMAL	INVERSION
1	3	0	18	4	61
	.145	0.000	.875	.194	2.966
2	4	2	20	10	50
	.194	.097	.972	.486	2.431
3	4	3	25	7	47
	.194	.145	1.215	.340	2.285
4	6	1	30	5	44
	.291	.048	1.459	.243	2.140
5	7	2	39	6	31
	.340	.097	1.896	.291	1.507
6	10	2	43	6	24
	.486	.097	2.091	.291	1.167
7	5	0	12	5	63
	.243	0.000	.583	.243	3.064
8	5	2	27	7	44
	.243	.097	1.313	.340	2.140
9	10	0	34	12	29
	.486	0.000	1.653	.583	1.410
10	10	2	51	3	19
	.486	.097	2.480	.145	.924
11	11	4	57	1	13
	.535	.194	2.772	.048	.632
12	21	4	45	6	10
	1.021	.194	2.188	.291	.486
13	4	4	44	3	31
	.194	.194	2.140	.145	1.507
14	8	5	46	6	21
	.389	.243	2.237	.291	1.021
15	9	7	43	7	20
	.437	.340	2.091	.340	.972
16	11	6	48	10	11
	.535	.291	2.334	.486	.535
17	17	1	44	5	19
	.826	.048	2.140	.243	.924
18	17	0	49	5	15
	.826	0.000	2.383	.243	.729
19	2	1	21	6	56
	.097	.048	1.021	.291	2.723
20	3	0	29	7	47
	.145	0.000	1.410	.340	2.285
21	4	1	32	11	38
	.194	.048	1.556	.535	1.848
22	5	1	35	9	35
	.243	.048	1.702	.437	1.702
23	7	2	38	7	31
	.340	.097	1.848	.340	1.507
24	11	3	39	7	26
	.535	.145	1.896	.340	1.264

APPENDIX D CONTINUED
249-452 FOOT LAYER

1	27	9	30	4	16
	1.313	.437	1.459	.194	.778
2	18	7	40	2	19
	.875	.340	1.945	.097	.924
3	25	4	31	3	23
	1.215	.194	1.507	.145	1.118
4	20	6	32	2	26
	.972	.291	1.556	.097	1.264
5	15	8	37	3	22
	.729	.389	1.799	.145	1.070
6	25	6	31	3	20
	1.215	.291	1.507	.145	.972
7	26	9	24	1	25
	1.264	.437	1.167	.048	1.215
8	30	3	27	2	23
	1.459	.145	1.313	.097	1.118
9	33	6	24	4	18
	1.605	.291	1.167	.194	.875
10	38	9	25	2	11
	1.848	.437	1.215	.097	.535
11	41	10	30	1	4
	1.994	.486	1.459	.048	.194
12	55	12	16	1	2
	2.675	.583	.778	.048	.097
13	66	7	13	0	0
	3.210	.340	.632	0.000	0.000
14	61	9	16	0	0
	2.966	.437	.778	0.000	0.000
15	52	14	20	0	0
	2.529	.680	.972	0.000	0.000
16	61	8	17	0	0
	2.966	.389	.826	0.000	0.000
17	46	14	26	0	0
	2.237	.680	1.264	0.000	0.000
18	45	7	27	0	7
	2.188	.340	1.313	0.000	.340
19	32	14	31	0	9
	1.556	.680	1.507	0.000	.437
20	28	10	34	2	12
	1.361	.486	1.653	.097	.583
21	18	12	44	1	11
	.875	.583	2.140	.048	.535
22	27	9	35	1	13
	1.313	.437	1.702	.048	.632
23	25	10	33	1	16
	1.215	.486	1.605	.048	.778
24	27	7	32	2	18
	1.313	.340	1.556	.097	.875

APPENDIX D CONTINUED
127-452 FOOT LAYER

1	1	0	66	0	19
	.048	0.000	3.210	0.000	.924
2	2	1	63	1	19
	.097	.048	3.064	.048	.924
3	3	0	59	0	24
	.145	0.000	2.869	0.000	1.167
4	5	0	55	1	25
	.243	0.000	2.675	.048	1.215
5	5	2	54	4	20
	.243	.097	2.626	.194	.972
6	6	2	56	0	21
	.291	.097	2.723	0.000	1.021
7	4	0	54	1	26
	.194	0.000	2.626	.048	1.264
8	4	1	56	0	24
	.194	.048	2.723	0.000	1.167
9	10	0	54	0	21
	.486	0.000	2.626	0.000	1.021
10	12	3	59	0	11
	.583	.145	2.869	0.000	.535
11	15	7	60	0	4
	.729	.340	2.918	0.000	.194
12	33	8	43	0	2
	1.605	.389	2.091	0.000	.097
13	14	12	60	0	0
	.680	.583	2.918	0.000	0.000
14	21	5	60	0	0
	1.021	.243	2.918	0.000	0.000
15	17	7	62	0	0
	.826	.340	3.015	0.000	0.000
16	15	4	67	0	0
	.729	.194	3.258	0.000	0.000
17	11	3	72	0	0
	.535	.145	3.501	0.000	0.000
18	13	8	60	0	5
	.632	.389	2.918	0.000	.243
19	0	1	73	0	12
	.000	.048	3.550	0.000	.583
20	1	1	69	1	14
	.048	.048	3.356	.048	.680
21	3	0	69	0	14
	.145	0.000	3.356	0.000	.680
22	4	1	65	1	14
	.194	.048	3.161	.048	.680
23	4	2	62	1	16
	.194	.097	3.015	.048	.778
24	7	5	56	1	17
	.340	.243	2.723	.048	.826

APPENDIX D CONTINUED
AVERAGE LAPSE RATE PER LAYER
LAYER 127 FT. TO 249 FT. -.229 DEG F.
LAYER 249 FT. TO 452 FT. -.670 DEG F.
LAYER 127 FT. TO 452 FT. -.899 DEG F.
THE FREQUENCY LAPSE RATE CONDITION PER LAYER
THE PERCENTAGE A LAPSE RATE CONDITION EXISTS PER LAYER

SUPER ADIABATIC	DRY ADIABATIC	LAPSE	ISOTHERMAL	INVERSION
127-249 FOOT LAYER				
194	53	869	155	785
9.435	2.577	42.266	7.538	38.180
249-452 FOOT LAYER				
841	210	675	35	295
40.904	10.214	32.830	1.702	14.348
127-452 FOOT LAYER				
210	73	1454	11	308
10.214	3.550	70.719	.535	14.980